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The Wider Application of Powder Metallurgy

By H. W. Greenwood

SOME attention has been paid in the United States to the increasing uses of powdered metal parts, but it is still true to say that in this country progress is slow, and, for the most part hardly inspired. Certainly there has not been any progress on a broad front, and from year to year the growth in the technique is small indeed. A comparatively recent statement from an American metallurgist has this to say—" An appreciation of the potentialities of powder metallurgy should make it possible for designers and production men to simplify the design of many parts and at the same time yield valuable cost economy." That is sweetly reasonable, but is it likely to bring about action either here or in America? Something more dynamic, much more positive is required if we are to see any notable advance in the application of powder metallurgy. What has been happening is a nice quiet progress, thoroughly justified by results so far as it has gone, but never by any chance approaching the revolution that we had hoped might take place. Did we ever ask ourselves why the revolution should take place? Still more pertinent is the question, what have we to offer to justify the revolution? We can, it is true, offer some quite remarkable examples of small parts which, produced by powder metallurgy, show savings of varying percentages up to perhaps 60%. This is conditioned by the production being large enough. We must have many thousand. pieces to produce before the saving is accomplished. Now it is not likely that any industrialist will undertake the installation of expensive plant in order to produce one, or even half a dozen pieces, out of his total requirements of perhaps half a hundred or more. Still less is it likely that anyone will set up the necessary equipment as a speculation in the hope that he will be able to find sufficient business to keep it going. The truth is that it is not so much the potentialities of powder metallurgy that we want to think about, as the ways and means of providing a vastly wider range of articles, powder metallurgy produced with very much smaller capital charges for installing plant. In other words we want to think along two main lines, one, increasing the range of articles we can produce by finding new and valuable uses for powder metallurgy products, and two, finding means of notably cheapening production either by much less costly presses, furnaces, dies, etc., or by radically altering processes so that they are speedier, more certain and more economical. Another useful line of advance would be in widening the range of properties that parts produced by powder metallurgy can offer, especially in certain desirable directions which, according to the function of the part, may be compressive or tensile strength, resistance to abrasion or to corrosion by various agents, higher electrical or thermal conductivity, greater hardness or ductility.

It does not require much thought to realise that in very many cases we have needlessly handicapped ourselves in the past by paying too much attention to tradition and to what were supposed to be the properties of metals. We have found that often those properties were largely dependent upon the provenance of that particular metal and that they were the result of conditions and were accidental. Sometimes it was impurities that were the causal factor, at other times heat treatment or the lack of it.

The fact that in powder metallurgy we are not bounded by the limitations of the phase rule has often been emphasised. It might well pay if we made more use of our freedom in this matter and sought to discover the principal directions in which real advantage might accrue. One is well aware that in drawing attention to freedom from the trammels of the phase rule there are many who do not immediately recognise just what these trammels are and so are unable to envisage the benefits that utilising the technique of powder metallurgy can confer. There could well be clearer and more detailed exposition of the advantages which powder metallurgy enjoys over the older technique of melting and casting. In particular a more careful study of those difficulties which are at present a handicap to the production of some alloy or metal having specially desired properties difficult to obtain by the classical metallurgical operations. Another powerful argument in favour of powder metallurgy is the certainty that the ordinary course of progress, the day by day demand for better properties, newer standards and more stringent specifications, will be amply sufficient to call for materials that, even now, the older metallurgical processes find difficulty in producing economically, and indeed from time to time fail completely.

It would not be exaggerating to say that hitherto powder metallurgists have tended to rest on their laurels. They have put forward the claim that their technique can and does produce materials impossible or extremely difficult to make in any other way. This applies to metals or alloys having a controlled porosity, and to combinations of metals which by reason of widely differing melting point, cannot be alloyed easily in the melting pot. These claims are true, but they are not enough. Bearings, for example, are an important part of any moving machine, but they are not the whole. In any case we in this country, as in America and elsewhere, have firms who are specialists in the manufacture of bearings by powder metallurgical as well as other methods and are quite capable of supplying the general requirements of the country. It is not, therefore, in this particular direction that we can look for notable expansion and development.

This very fact should assist in directing our thoughts toward the rational expansion of powder metallurgy

and point the way in which development may, and probably will take place. As we cannot expect a manufacturer to instal plant suitable for the production of small porous parts such as bearings or liners when he can buy them at competitive prices in the open market, why should we expect him to produce other small parts representing only a very small fraction of his requirements, the production of which will involve him in heavy capital expenditure? The fact that some of these small parts are of a highly specialised nature, and that they are, for example, in the case of cemented carbide tool tips or other parts, produced at highly competitive prices, renders it extremely unlikely that any general manufacturers could produce such parts more cheaply than the market can supply them. Yet it is probably not a great time ahead before we shall require a wider variety of such parts, and of much more complex composition having properties which will mark a very big advance on anything we have at the present time. The answer to our problem of to-day is the intensive development and study of production by powder metallurgical methods at the hands of several firms who already have plant and a knowledge of the technique, and who are prepared to undertake production on behalf of outside consumers. This really means that only a firm or firms having sufficient business to earn "bread and butter" can hope to weather the period during which research and development is taking place.

On any serious assessment of the position of powder metallurgy to-day it must be admitted that the progress of the past four or five years offers an entirely different prospect to that which appeared reasonable at the close of the late war. The real advances that have been made since then not only in the development of the basic technology of powder metallurgy, but in the use of metals such as titanium, zirconium and others, the rapid progress that has followed the earlier work in impregnating porous compacts with another metal, the very obvious need there is for much more refractory metals than we at present possess, the remarkable potentialities that combinations of refractories and refractory metals offer, along the line of the Cermets, all these are evidence of the more favourable possibilities that offer themselves to those who have facilities to exploit present conditions.

It would seem that the day is passed when the practice of powder metallurgy was confined to the production of component metals for electrical purposes and porous bearings, and that in the not distant future the powder metallurgist will, willy nilly, be called upon to produce metals and alloys of new compositions and properties, and conforming to specifications in both composition and properties that even to-day we may consider impossible. What is more the general progress in technology will depend upon powder metallurgy for the supply of parts that alone will stand up to the stress and strain of industry and production to-morrow. Even to-day we are realising that in the special alloy steels, and in the newer, heavier and more refractory metals, we have travelled a long way from the metallurgy of 1938/39.

If powder metallurgy is to give the assistance and the production to our metal and other industries that we require we shall have to do some strenuous thinking on the educational aspects of the subject, as well as on its other facets, for at the moment there is little upon which we can congratulate ourselves. We have no lectureships on the subject, still less professorships, yet we are going to want both badly in the not distant future.

Super Purity Aluminium Sheet

THE increasing costs of copper, lead and zinc and doubts about long-term availability of lead, in the post-war years have encouraged the development of alternative materials, particularly for the use of flashings, weatherings and gutter linings. The requirements of an alternative metal for these purposes are exacting in that it must compare favourably with the traditional metals in durability, and must be sufficiently ductile, and, at the same time, must be competitive in price. It must not necessitate any serious changes in building practice and must have the required degree of workability.

With these points in mind the building industry has made considerable progress with the use of commercial purity aluminium of 99·0–99·7% purity for flashings. However, the general adoption of normal commercial purity aluminium for flashings and weatherings has been hampered by a certain lack of ductility in comparison with lead. As a result of developments in the production of super purity aluminium sheet of 99·9% purity this difficulty has now been overcome. This material has a remarkably high measure of ductility and in this respect compares favourably with lead. It can be worked to shape in a way that is much nearer to lead than other non-ferrous metals.

Ordinary commercial purity aluminium has a proved record of reliability in the building industry and many case histories of its use, in widely different climates and conditions, could be cited, in particular, convincing evidence of its durability for roofing. As with other industrial metals, it is more appropriate to certain conditions of service. There are special industrial conditions for which aluminium is particularly well suited and where, in fact, other metals rapidly deteriorate. It has a specially good record of service in industrial areas in the vicinity of railway stations, gas works, etc., where sulphurous fumes are strong. One example of the use of aluminium as an alternative to other metals is on the roof of a pickle factory where acetic acid fumes are so concentrated as to have perforated 5 lb. lead sheet (0·084 in. thick) in under three years and where super purity aluminium is now in use.

Large-scale production of this super purity aluminium sheet has been developed by The British Aluminium Co., Ltd. and is now available in coils 12, 18, 24, 30 and 36 in. wide, the 12 in. coils being 14 lb. in weight and having a coverage of 35½ sq. ft., the remaining coils weighing approximately 28 lb. and having a coverage of 71 sq. ft. It is noteworthy that the 22 S.W.G. super purity sheet recommended for flashings, which is available in 1 ton lots or over at 2s. 10d. per lb., is cheaper than copper and zinc and about one-third the price of lead on a coverage basis, as is shown on the following data summarising the relative costs of the main flashing materials :—

	Shillings per sq. ft.
Super purity aluminium at 2s. 10d. a lb.—22 S.W.G.	1·2
Zinc (£103 10s. ton), 21·57 oz.—15 zinc gauge (0·036 in.)	1·25
Copper (£207 10s. ton), 16 oz.—24 gauge	1·85
Lead (£105 5s. ton), 4 lb.	3·76
Lead (£105 5s. ton), 5 lb.	4·7

Under present conditions this super purity aluminium not only fulfils workability and service requirements but assists the building industry in giving some effect to the need for reduced costs.

Steelmaking by the Basic Process

Steel Industry's Debt to Sidney Gilchrist Thomas

By V. S. Swaminathan, M.A., M.Sc.(Lond.)

The steel industry throughout the world is indebted to Sidney Gilchrist Thomas for a discovery which revolutionised steelmaking. His work made possible the exploitation of vast phosphorus-bearing iron-ore deposits, the phosphorus contents of which could not be removed in the acid-lined furnaces then wholly used. Thomas solved this problem by the provision of a basic lining capable of removing phosphorus from a bath of metal and, to-day, the bulk of steel manufactured is produced by the basic process he discovered; it is fitting, therefore, that, this month being the centenary of his birth, special mention should be made of his discovery and its effects.

FOR metallurgists, engineers and farmers the most important centenary of 1950 is the birth of Sidney Gilchrist Thomas. When in 1878 Thomas and his cousin Gilchrist announced their discovery of basic linings for steel furnaces they solved one major problem which beset that key industry. It was the provision of a furnace lining in which lime could be used to remove phosphorus from the bath of metal, and form a slag. Before, only acid-lined furnaces of silica brick were used, in which lime could not be worked, and phosphorus could not therefore be removed from the raw material. Both Bessemer and Siemens, though they revolutionised steel manufacture, were limited before this discovery to the use of phosphorus-free iron ores and pig iron.

Sidney Gilchrist Thomas

The work of Thomas and Gilchrist thus rendered possible exploitation of the vast phosphorus-bearing iron ore deposits throughout the world, and to-day the bulk of steel manufactured is produced by their basic process. In 1946 and 1947, for example, 87% of the production of countries responsible for 81% of the world output of steel was basic. Even when ill, and living for a time in Algiers, Thomas experimented with basic slag as an artificial fertiliser, thus placing agriculture as well as engineers in his debt. This discovery of the treatment of phosphoric pig iron had, moreover, a most interesting effect on non-ferrous metallurgy, for the basic converter may be said to be the starting point of present-day treatment of copper and nickel. Hence in the history of discovery and invention the name of Sidney Gilchrist Thomas assuredly occupies an honourable place. His centenary is being commemorated at a meeting of the Iron and Steel Institute, in London, on April 26th.

Thomas's Activities

Considering Thomas's occupation, environment and straitened financial circumstances, the shortness of his life (he lived only to the age of 34) and the immense and varied benefits which flowed from his work, his story is almost without parallel in the annals of technology. Son of William Thomas, a Welshman in the solicitor's department of the Inland Revenue office, and his wife Melicent, eldest daughter of the Rev. James Gilchrist, Sidney Gilchrist Thomas was born in Canonbury, London, on April 16th, 1850, and studied at Dulwich School. Even as a boy he manifested a strong bent towards applied science. His father's death when he was only 17 led to Thomas abandoning all ideas of qualifying for a profession, and taking up a clerkship in the Marlborough Street Police Court, from whence he was transferred to Thames Police Court, Stepney. After making himself competent in his official duties the young clerk took up the study of chemistry and physics in earnest.

A sentence used by Mr. Chaloner, teacher of chemistry at the Birkbeck Institution, in the course of a lecture which Thomas attended, impressed itself deeply on his mind : " The man who eliminates phosphorus by means of the Bessemer converter will make his fortune."

From then on, seeking a solution to this problem became the ruling passion of his life. Thomas made innumerable experiments at home, assiduously attended the laboratories of various chemistry teachers, and spent his annual holidays visiting iron works at home and abroad. He passed all examinations qualifying for the degree of metallurgy awarded by the Royal School of Mines, but was denied it because he was unable to attend the daytime lectures as decreed by regulations. From 1874 onwards he was a contributor to the technical journal *Iron*.

Most inventions have their pedigree, and Thomas's was no exception. When in 1855 Bessemer built his acid converter with a siliceous lining its product was irregular, and phosphorus showed itself antagonistic to the satisfactory working of the process. A French scientist—Gruner—pointed out why it was hopeless to dephosphorise pig iron in a converter having a siliceous lining, and showed the conditions which had to be met for removing the phosphorus, namely, the necessity of working with a basic slag, and of using a basic lining. Towards the end of 1875 Thomas arrived at a theoretical and provisional solution of the problem of dephosphorisation. His conclusion was that the converter's lining had to consist either of lime, magnesia or dolomite. He at once aimed at dephosphorisation of pig iron, and recovery of phosphorus, destined later to form a product of great value to agriculture. He communicated this "basic" theory to his cousin, Percy Gilchrist. It was only in 1877 that Gilchrist agreed to carry out a few experiments at the Blaenavon Works in Wales, where he had charge of the laboratory. Their first patent was taken out in November that year. Mr. E. P. Martin, Manager of the Blaenavon Works where Gilchrist was employed, was admitted into the secret early in 1878, and proved most helpful.

Basic Process Patented

Thomas made a first communication of the process in March, 1878, which passed unnoticed. The complete specification of the patent was filed two months later. A paper the author read at the Spring Meeting of the Iron and Steel Institute was received with a certain measure of scepticism. A further communication, prepared by Messrs. Thomas and Gilchrist for the Autumn Meeting, stated that, on the basis of the work by Gruner, the authors had abandoned the lining of lime (which was of insufficient strength), that magnesite was too costly, and so dolomite was employed. It took place in Paris, but the paper was neither read nor discussed. Fortunately in the visits to works which followed, especially at Le Creusot, metallurgists discussed various points of the new process with Thomas. Trial casts in England were decided upon. Mr. E. W. Richards, Manager of Messrs. Bolckow, Vaughan & Co's large iron works in Cleveland, became a convert to Thomas's views. In April, 1879, large-scale experiments were successfully carried out at that Company's Middlesbrough establishment, which at once secured the practical commercial triumph both of the process and of the inventor. Thomas proved that he had solved the problem by substituting in the Bessemer converter a durable basic lining for the former siliceous one, and he avoided "waste of lining by making large basic additions, so as to secure a highly basic slag at an early stage of the blow." At long last, the treatment of phosphoric pig iron in the converter became an industrial reality.

Applications of the Process

In mid-1879 two well-known French iron-masters, Messrs. Henri Schneider and Henri de Wendel, entered into relations with Thomas, and the process was soon in full operation at Le Creusot and at Joeuf. In September that year, the first basic Bessemer blow was carried out in Germany. The "Thomas" process rapidly met with the most remarkable success both in England and on the Continent. As early as 1880 over sixty basic converters were in operation, and upwards of 350,000 tons of basic Bessemer steel were produced. Four years later world production of "basic" steel amounted to 864,700 tons. In 1889 world output rose to 2,274,552 tons, when there were also produced together with basic steel 700,000 tons of phosphoric slag. In 1895 England and Germany alone accounted for 2,898,476 tons of basic steel and about one-third that tonnage of basic slag. The process developed far more rapidly on the Continent than in Britain. Thus whilst in 1890 Continental production of basic Bessemer steel exceeded 2,000,000 tons that of Britain was only 400,000 tons.

There are reasons for the retarded development of the basic Bessemer process in Britain. Domestic lean ores are too siliceous in character; the pig irons produced from them contain too much silicon, or too little manganese; and it is necessary to use a certain proportion of imported manganiferous ore as part of the blast-furnace charge to obtain the necessary composition for the fluid metal. On the other hand, native German, French and Austrian ores, though highly phosphoric, yield pig irons suitable for the basic Bessemer process. Too much silicon in a basic charge yields an acid siliceous slag, which may attack and seriously damage the basic material with which the converter is lined. Silica also retards dephosphorisation. It is, therefore, necessary to use some other element as the chief internal fuel. The most suitable irons are those containing considerable amounts of manganese with as low a silica content as possible. The manganese generates heat during its oxidation to oxide which is basic in character, and counteracts acidity due to oxidised silicon. It prevents over-oxidation of the metal, and tends to eliminate sulphur although to a limited extent only. The oxidation of phosphorus is extremely exothermic, and this supplies the heat in the later stages of the process.

The basic open-hearth process was being developed at the same time, and the greater ease of control and latitude of working, coupled with the better quality of product afforded by it, gave rise to a preference for steels so made. In 1904 basic open-hearth steel production exceeded that of basic Bessemer, and during the past four decades there has been an almost continuous decline in the amount of steel made by the latter method. This is due in no small measure to the basic Bessemer product not being admitted to B.S. specifications, and to British demand for cheap basic Bessemer steel being satisfied by imports of low-priced "semis" from the Continent. From 1926–1934 no steel was produced by basic Bessemer process in Britain, apart from a very small quantity in 1929. In the 'thirties two plants for basic Bessemer production were completed by Stewarts & Lloyds at Corby and Richard Thomas & Baldwins, Ltd., at Ebbw Vale. The first blows of these plants took place at the end of 1934 and 1938, respectively.

These two plants are essentially similar in general lay-out and operation. All the vessels are of 25-ton

capacity. The blast-furnace iron entering the mixers at Corby averages 2% phosphorus and 0·1% sulphur, the latter element ranging from 0·04–0·3% in individual cases. Soda ash is used for desulphurising iron, first at the blast furnace and again between mixer and converter, so that the sulphur content is reduced to between 0·05 and 0·06%. The addition of lime to the converter in the basic operation further reduces sulphur so that little difficulty is experienced in making steel of 0·04% maximum sulphur. Basic linings are used in steelmaking furnaces other than the open-hearth, but in U.K. the basic open-hearth process has outstripped the rest in tonnage :—

U.K. STEEL PRODUCTION (IN 1,000 LONG TONS)

	Bessemer Ingots and Castings		Open-hearth Ingots and Castings		Electric Steel†	Other Methods	Grand Total
	Acid	Basic	Acid	Basic			
1947 ..	207·9	678·2	1,228·8	9,869·9	575·7	164	12,724·5
1948 ..	218·3	786·2	1,398·3	11,589·3	706·9	177·6	14,876·6

† Probably at least 90% basic.

No country benefited more from Thomas's work than France. In December, 1932, meetings were held in Paris, under the auspices of the Société des Ingénieurs Civils de France, to mark the jubilee of the introduction of the Thomas-Gilchrist process into that country. It was then stated that of 9,447,000 tons of steel produced in France in 1930, 98% was manufactured by the basic process, and 1,478,000 tons of phosphoric slag marketed. When made with ordinary care basic converter steel for rails met every mechanical and chemical condition required of acid Bessemer steel. One effect of this introduction was the establishment of large steel works in the eastern region of France.

On the Continent, works situated in the Minette basin, in view of their vast and rich ore deposits, will doubtless continue to expand the capacity of their Thomas plants as is provided for in the French Monnet Plan. Thomas steel costs at these works are unlikely to be bettered by any other country in the world, for which reason they are likely to intensify their efforts in the export direction.

Future of the Process in Germany

In Germany the future of Thomas process will be influenced to a marked extent by the possibility of obtaining phosphoric ores from Sweden or the Minette basin. It has become a composite part of the integrated German works, even though ore supplies may be difficult, as the process is well-nigh indispensable from the standpoint of energy distribution alone—i.e., gas and current supplies. When the last war broke out nearly three-fifths of German production was open-hearth steel, and the rest basic Bessemer steel. There was a slackening in the relative progress of the Thomas process during the inter-war years, due to the combined effect of raw material supplies, lowering of consumer demands and the effect of the grid system practised on such an extensive scale in Germany in the integrated iron and steel works. Power supply in the Ruhr is extensively linked up with the production of Thomas pig iron and steel as sources of energy. The Bessemer process uses almost 100% pig iron compared with the open-hearth which utilises considerable scrap. The fuel consumption per ton of Bessemer steel, including that used in making pig iron, is therefore more than twice that for the open-hearth steel. Even so, the energy available for other plants, or for civilian requirements, is much greater than when the open-hearth process is used on account of coke-oven and blast-furnace gas produced as by-products in making pig-iron. These, coupled with the need for phosphatic fertilisers by farmers, contributed to the important position of the basic converter in integrated German steel plants. Several works operate vessels of 30–60 tons capacity. In wartime it became imperative to use Thomas steel for products of a quality normally produced in the open-hearth. Since low nitrogen content is frequently required in applications a special study of this problem was made. Methods to control nitrogen included the addition of ore, shallow bath blowing and side blowing. At the Reichswerke in Watenstedt a double blowing technique was developed in which only 25–30 tons of pig iron were charged initially in a 50-ton converter and blown with the entire lime charge at normal pressure until the phosphorus was reduced from 1·75–0·1%. The remaining 20–25 tons of hot metal was then added and the blow completed. Claims made for this procedure are : shorter blowing time, reduced spitting from the converter, higher ferric yield and lower phosphorus, nitrogen and sulphur contents. Side-blowing in a specially altered 30-ton vessel was apparently the most successful technique, the bulk of the product finishing nitrogen in the range of 0·006–0·008%. To sum up, development from the standpoint of quality is being pursued generally to enable the works to achieve a low-nitrogen, low-phosphorus mild Thomas steel capable of deep drawing. Whether such a steel can be produced as a result of metallurgical developments alone, or by changes in the construction of the converter is a question which must be left to the future. In the meantime more attention is being paid to temperature control during the blowing of the charges and to increasing the durability of the converter.

Outstanding Events in Thomas's Short Career

Highlights in the all-too-short career of Thomas, whom the Rt. Hon. W. E. Gladstone called " a rare young man " are briefly told. He was possessed of great financial ability, and had a thorough knowledge of English and Continental patent law. He was careful to secure his inventor's rights not only in Great Britain but also on the Continent and in the United States. He thus came by the " fortune " predicted by Mr. Chaloner. Thomas's visit to the United States early in 1881 proved singularly successful. A year later he was elected a Member of Council of the Iron and Steel Institute, and the following year awarded its Bessemer gold medal. The last few years of Thomas's life were occupied in a fruitless search for health. After spending several months at Ventnor and Torquay he made a prolonged voyage *via* the Cape, visiting India and Australia, and returning through the United States. He later lived for a time in Algiers, and died in Paris in February, 1885, worn out by his labours, but in the hour of his triumph, and was buried in the small Passy Cemetery. From the first, Thomas held "advanced" political and social views, and he intended to devote his fortune to ameliorate the lot of workers. He bequeathed this intention to his sister as a sacred trust. After a modest provision had been made for her and his mother, the inventor's money was spent on philanthropic objects. There is a portrait of Thomas in oils by Mr. Herbert Herkomer, R.A., executed from photographs after death. In the history of discovery and invention the

name of Sidney Gilchrist Thomas occupies an honourable place as one of the creators of the "Age of Steel."

Problems Raised by the Process

If the discovery of Thomas and Gilchrist solved one major problem it posed another. It brought in its train difficulties connected with the mechanical characteristics of basic refractories. Even to-day nearly all basic open-hearth furnaces in operation are not wholly composed of basic bricks, but use in varying amounts silica bricks of the sort of which acid furnaces are normally constructed throughout. The anomaly of the continued use of acid bricks in basic furnaces is, in part, a consequence of the relatively high price of basic bricks, which are four to five times more expensive than silica bricks. The problem is one of building an all basic furnace to take maximum advantage from a higher working temperature, and the minimum disadvantage from the high price, the spalling and the mechanical weakness to which the basic brick is subject.

One aim of research in the British steel industry is to increase the yearly output of basic open-hearth furnaces by using basic refractories where at present silica refractories are employed. The British Ceramic Research Association and the B.I.S.R.A. have a joint Steelmaking Refractories Committee. A sub-committee stimulates and observes trials of all-basic furnaces in steel works in various parts of the country and then "spreads the news" of the results obtained. It circulates to industry recommendations on manufacture of bricks and design and construction of furnaces. The first two post-war all-basic furnaces went into service in November, 1948. These, as well as three others, have completed "campaigns." The goal, in short, is to develop an all-basic open-hearth furnace, whose longer life and greater output will justify the greater cost of bricks and of construction. Based on the quite modest figures quoted by the Lancashire Steel Corporation before the war of a 100-ton superiority per week by an "all-basic" against a "normal" basic furnace, a proportionate increase in all the basic open-hearth production of Britain would give over a million tons extra steel each year from existing capacity, but a greater relative increase is hoped for. Full-scale experience now being obtained with "all-basic" furnaces suggests that an increased output of up to one-fifth on a large proportion of U.K's capacity may well prove feasible.

For keeping down stresses in roof bricks of open-hearth furnaces, the most widely known arrangements are the Radex design formulated in Austria before the war, and the Detrick development in the United States. The Austrian design consists essentially of a spring-loaded "skewback" channel to take care of the expansion and contraction, and a series of ribbed courses, the bricks of which are ribs suspended from curved girders fitted across the furnace at intervals. Between the ribbed courses there are three or five courses of smaller bricks which have no support other than the natural arch except for keying or jointing on to the rib bricks. The Detrick method relies on the suspension radially from the superstructure of every roof brick. The latest designs use a "sprung" arch system, in which every brick is suspended, but where the side pressure is maintained by spring loading. A member of the staff of the Steel Peech and Tozer branch of the United Steel Companies has devised a weight-lever system which acts automatically on the "skewback" and roof ribs to control the roof. Brick suspension also forms part of this method.

Effect of the Process on the Treatment of Non-ferrous Ores

Thomas's discovery has had a most interesting effect on non-ferrous metallurgy, since the basic converter forms the starting point of present-day treatment of copper and nickel ores. The concentration of copper matte by an air blast had been tried but without satisfactory results. In 1878, soon after Thomas's discovery, Holway, an English metallurgist, endeavoured to utilise the basic converter to free copper from two elements which were then deemed particularly objectionable—antimony and arsenic; and on the basis of their analogy to phosphorus he hoped to form arsenates and antimonates. The attempt failed, but it formed very probably the basis upon which researches were made in France in 1879 by David and Manhes at Eguilles near Avignon. In 1880 treatment of copper matte in the acid converter was established, and it was employed extensively in the United States three years later. About the same time the metallurgy of nickel rapidly developed following the discovery of garnierite ore bodies in New Caledonia. The method of transforming the silicate into sulphide was being established, and the converter was resorted to for removing iron from the matte. About 1908 Pierce Smith in the United States hit upon the idea of using a converter having a basic lining of magnesite bricks, and carrying out the scorification of the iron oxide produced by silica added during the process and not by that taken from the converter lining. It was, however, necessary to protect the magnesite lining from the acid and destructive action of the added silica. This was later accomplished by the adoption of a remarkable scientific and technical "dodge," which consisted in forming, on the magnesite lining, a kind of protective varnish. To obtain this, molten matte was poured into a new converter and the blast started up as in normal working, but instead of stopping at the ferrous oxides stage, the charge was subjected to an after-blow, without, however, adding silica. Ferric oxide was produced, the converter was tilted up and down, became cool and the magnetic oxide was deposited on the entire lining, protecting it against the destructive action of silica. This technique of operation was extended to nickel metallurgy. Thus the basic converter completely transformed the treatment of nickel ores, and placed it on an industrial footing. The Thomas process thus led indirectly to the building up of modern methods followed in copper and nickel metallurgy, which by a singular course of development had proceeded from an acid converter to the basic converter in which an acid was utilised.

B.O.C. Prize for Welding Research

In 1940 the Council of the British Welding Research Association accepted an offer from the British Oxygen Co., Ltd. to provide a prize fund for a competition relating to welding for three years.

This year, a single prize of £100 is again offered and will be awarded for the best paper submitted on a research into welding or its applications, carried out in Great Britain or Northern Ireland. Details of the regulations governing the competition may be obtained from the Secretary of the Association, 29, Park Crescent, London, W. 1.

Some Properties of Tantalum

By Rupert H. Myers, M.Sc., Ph.D.*

An investigation of the effect of deformation and annealing on some mechanical and physical properties of tantalum has been made and the phenomenon of hardening of tantalum when heated in an imperfect vacuum has been described and studied. Deformation lowers the softening temperature from 650° to 450° C., but has no effect on the electrical resistivity.

A STUDY of the effect of deformation and annealing on the mechanical properties of tantalum was undertaken as part of a programme designed to elucidate the metallurgy of this metal. Very early in the investigation, however, an unusual phenomenon was encountered, namely, the hardening of tantalum when it was heated to temperatures of the order 1,800° C. This was first reported in a paper describing early work on the preparation and consolidation of electrolytic tantalum powder.[1] Subsequently, a series of specimens of tantalum wires, which had suffered amounts of deformation varying from 10 to 80% reduction in area, was heated for 20 minutes to various temperatures in a vacuum sintering unit[2] with a view to obtaining a rough survey, by means of hardness measurements, of the annealing temperature of tantalum. The hardness was measured on the diametrical longitudinal polished section of each wire. In all cases, and with no apparent simple relation to the prior amount of deformation, there was a large increase of hardness with a peak at approximately 1,800° C. A typical curve is shown in Fig. 1.

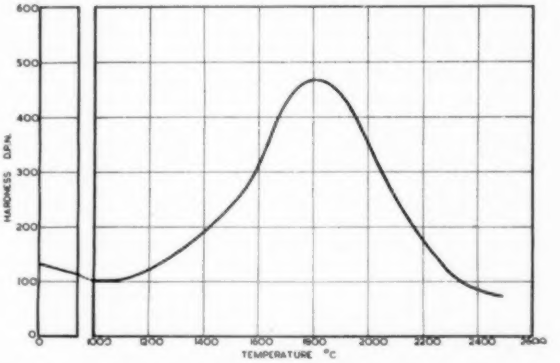


Fig. 1.—Typical curve showing hardness increase in tantalum after heating.

It was thought at first that the phenomenon might have been due to age hardening but the hardness increases were of a different order of magnitude from those usually encountered with these changes. Several experiments were performed in an endeavour to clarify the position. In all cases, except where specifically stated, the specimens, which were heated in the sintering unit, were cooled by radiation to the cold walls of the bell by turning off the heating current. The cooling rate depended on the length and diameter of the wires, but they usually cooled from incandescence to below red heat in a few seconds. The pressure in the sintering unit in all these experiments was at the most 10^{-3} mm. Hg as measured with a McLeod gauge.

(*a*) A piece of fully annealed (2,600° C.) tantalum wire was reheated to various temperatures and hardness determinations were made. It was found that the hardening occurred over the same range as for the deformed specimens. Apparently the phenomenon was not connected with prior deformation.

(*b*) A length of wire was heated in the sintering unit to 2,600° C. for 20 minutes and then the temperature was lowered rapidly to 1,800° C. and held there for a further 20 minutes. After this time the current was turned off and the wire allowed to cool. This wire was hard. Reheating the wire for a further 3 hours at 1,800° C. caused no detectable change in the hardness. Heating to 2,600° C., however, returned the hard brittle wire to its former dead-soft condition.

(*c*) When hardened specimens (i.e., those heated to 1,800° C.) were reheated to temperatures below 1,800° C. no change in hardness was observed.

(*d*) It has been mentioned that wire heated to 2,600° C. and rapidly cooled was soft; however, it was found that specimens cooled from 2,600° C. to room temperature at the rate of 5° C. per minute were hard.

(*e*) The hardening occurred with tantalum from three different sources and appeared to be uniform throughout the specimen. In none of the samples of tantalum, hard or soft, was a second phase detected using either microscopic or X-ray examination.

These experiments indicated that the phenomenon was probably not due to age hardening, and the X-ray pictures of the hard and soft tantalum gave no evidence of allotropy. Measurement of the lattice parameter of the two specimens gave the following results :—

$$\text{Ta (soft) a} = 3{\cdot}2964 \text{ Å}$$
$$\text{Ta (hard) a} = 3{\cdot}3060 \text{ Å}$$

This indicated that a very considerable expansion of the lattice had taken place (approximately 0·3%) and it was thought that the hardening may have been due to the absorption of a gas or vapour. Concurrently with these experiments work on the sintering of tantalum powder was being performed and the results obtained there supported the gas hardening theory. Further evidence was obtained when the electrical resistivity of tantalum wire was measured. The same piece of wire was used in all the determinations and the values were measured in the order given in Table I.

* Formerly of the Baillieu Laboratory, University of Melbourne, now a member of the Australian Commonwealth Scientific and Industrial Research Organisation's team at the Atomic Energy Research Establishment, Harwell, Berkshire.

1 Myers, R. H., *Proc. Aus. I.M. and M.*, 1946, **144**, 15.
2 *Ibid*, 1946, **144**, 45.

TABLE I.—SPECIFIC ELECTRICAL RESISTIVITY OF TANTALUM HEATED AND COOLED UNDER VARIOUS CONDITIONS

Condition of Wire	Specific Electrical Resistivity micro-ohm.cm. (20° C.)
i Drawn (60% reduction in area)	13·1
ii Annealed 2,600° C.—rapidly cooled—soft ..	13·1
iii Reheated to 1,800° C.—rapidly cooled—hard	17·4
iv Reheated to 2,600° C.—rapidly cooled—soft	13·1

It will be seen that the hard wire had a higher resistivity ($17{\cdot}4 \times 10^{-6}$ ohm.cm.) than the soft wire, but that the original soft condition could be restored by the high-temperature treatment. It was known that the electrical resistivity of metals was affected considerably by impurities so that the above results supported the gas theory.

It was discovered ultimately that the metallic bellows used in the water cooling of the grips in the vacuum heating unit did not remain gas tight under the intense irradiation from a hot bar or wire and that air (trapped at the extremities of the convolutions) or water vapour or both entered the system during a heating run. Provision of reflecting shields to protect new bellows overcame this trouble.

In an effort to establish whether the hardening was due to water or air (or both), soft specimens were heated to 1,800° C. in the bell with :—

(i) A steady leak of air such that the pumps could just maintain the pressure at 10 microns.

(ii) Some drops of water on the base plate.

In both cases the specimens were hardened. As a result of this it was thought that the main cause of the hardness increase was oxygen. Because of the readiness with which hydrogen could be pumped out of tantalum at 650° C. it seemed unlikely that this gas could be responsible for the phenomenon. As has been explained in detail elsewhere[3] the heating of the wires to temperatures above about 2,200° C. resulted in the expulsion of the absorbed gases. Rapid cooling through the critical range prevented any detectable re-absorption and soft metal resulted.

As the heating of tantalum specimens in the altered sintering unit to temperatures of the order 1,800° C. was still accompanied by a hardness increase of approximately 20 D.P.N. due probably to small amounts of adsorbed water vapour on the walls of the vacuum bell, it was decided to try alternative methods of heating. Two systems were used, namely, a clear silica tube heated by radiation from a wire-wound furnace, and a high-frequency induction unit where the specimen alone was heated. Rotary and oil diffusion pumps with suitable baffles were used in both cases. The pressures were not more than 10^{-4} mm. Hg. The results obtained with the samples of tantalum in the silica tube showed that no increase in hardness occurred up to 900° C., but that the system was not sufficiently gas-tight at temperatures above 950° C. In the case of induction heating—the specimen being suspended in the coil by means of tantalum wire—an increase of hardness of up to 30 D.P.N. over the critical range was noticed. When the specimens were heated in a closed tantalum cylinder in the induction coil, however, no hardness increase was obtained at any temperature. The tantalum container apparently shielded the samples completely from any residual gases and vapours in the system.

The samples of deformed tantalum wire which were used in the preliminary annealing work described earlier were examined microscopically in an endeavour to determine the temperature at which recrystallisation occurred. The results are presented diagrammatically in Fig. 2. The " average number of grains across a longitudinal section " was chosen as giving a measure of the grain size in the specimens. It was interesting to note that the elongated grains in the drawn wires could not be observed to break down into a number of smaller grains but appeared to change straight from elongated to large equi-axed grains. In view of information gained from later work the data should probably be more correctly labelled as the temperature at which grain growth began with various amounts of deformation prior to heating. A study of the changes by means of X-rays is being undertaken.

The problem of etching the tantalum specimens was a difficult one because of the chemical resistance of tantalum to most common reagents. Hydrofluoric acid was the only acid which would produce any etching and this was always accompanied by pitting. Very many additions to hydrofluoric acid were tried, amongst these being hydrochloric, nitric and sulphuric acids, potassium fluoride and oxalic and tartaric acids. Other etchants tried were solutions of potassium carbonate, hot and cold, concentrated and dilute potassium hydroxide, potassium fluoride, and potassium fluoride with tartaric and oxalic acids. The best etchant found to date consists of cold concentrated nitric acid with 5% of concentrated hydrofluoric acid (40%) added.

With this background of the problems encountered in the early work, it is proposed now to describe the results of experiments designed to study the effect of deformation and annealing on some of the properties of tantalum.

Effect of Deformation on some Properties of Tantalum

(a) Mechanical Properties

The effect of deformation on the ultimate tensile strength, elongation and hardness of tantalum was

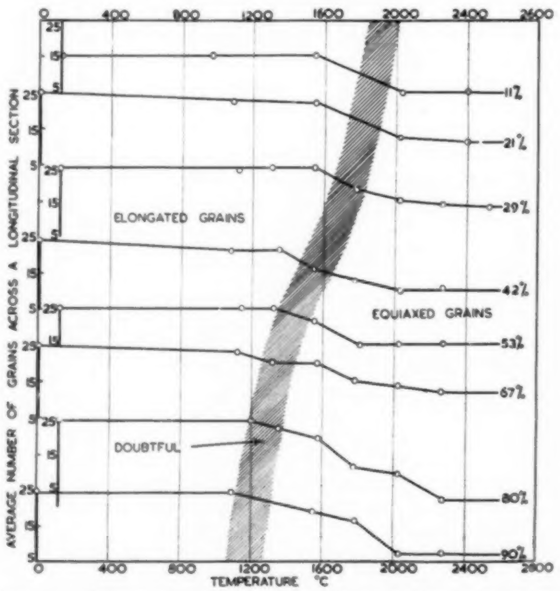


Fig. 2.—Diagrammatic representation of micro-structure of deformed tantalum after heating in vacuo.

3 Myers, R. H., *Metallurgia*, 1948, 38 (228), 307.

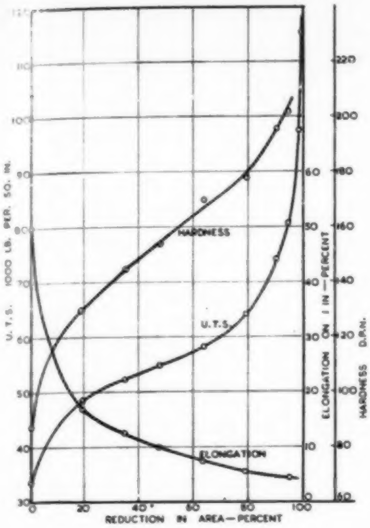


Fig. 3.—Curves showing the effect of deformation on the hardness, ultimate tensile strength and elongation of tantalum.

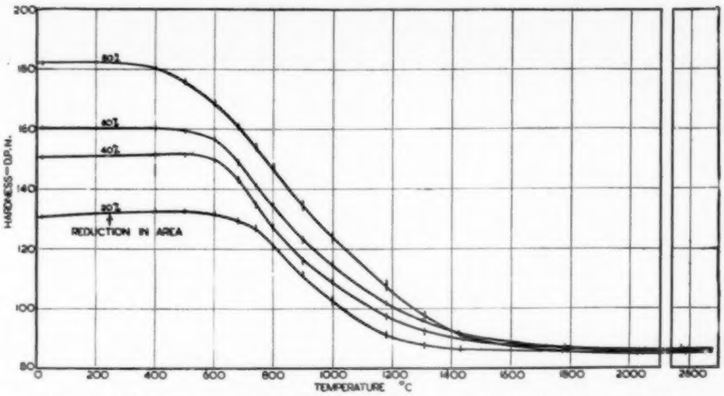


Fig. 4.—Hardness of deformed tantalum after heating at various temperatures in vacuo for 30 minutes.

studied using as the starting material 0·1 in. diameter tantalum rod, annealed at 2,600° C. in a vacuum of 10^{-4} mm. Hg. pressure.

Qualitative spectrographic analysis of this metal indicated the following impurities :—

Ni	trace
Fe	,,
W	faint trace
Cu	,,
Ca	,,
Si	,,
Cb	not detected
Pb	,,
Sn	,,
Cr	,,

Chemical analysis was employed to check iron and nickel with the following results :—

Fe less than 0·02%
Ni less than 0·01%.

The deformation was supplied by wiredrawing using techniques already described.[4] The results of this series of tests are plotted in Fig. 3. It will be seen that tantalum could easily withstand a deformation of 99% reduction in area by wiredrawing without annealing and that this increased the ultimate tensile strength from 33,500 to 115,600 lb./sq. in.—a factor of 3½. The hardness after 90% reduction in area was 200 D.P.N. (88 D.P.N. annealed) and the good ductility of the metal was reflected in the elongation values—50% in the annealed state and 5% after 90% reduction in area.

(*b*) *Electrical Resistivity*

As noted earlier, in Table I, deformation had no effect on the electrical resistivity of pure tantalum, the value at 20° C. being $13 \cdot 1 \times 10^{-6}$ ohm.cm. The temperature coefficient between 20° and 100° C. was determined to be $0 \cdot 0472 \times 10^{-6}$ ohm.cm./° C.

(*c*) *Annealing Temperature*

It was abundantly evident that extreme precautions would have to be taken to protect the tantalum specimens from contamination by gases and vapours since the hardening due to gas absorption would mask the softening due to annealing. The general plan was to heat samples of tantalum wires, which had been deformed various amounts by wiredrawing, to various temperatures, in as high a vacuum as practicable and to measure the hardness along the axes of the diametrical longitudinal metallographically polished sections. One precaution taken before the heating was to remove completely the anodized and lubricant-impregnated film from the drawn wires using a fine emery cloth. For temperatures up to 900° C. the specimens were encased in molybdenum cylinders and heated in a silica tube. The metal casing was to prevent the tantalum from coming into direct contact with any oxygen containing material. For temperatures above 900° C. induction heating with the samples in a closed tantalum tube was employed.

The approximate rate of cooling after heating at each temperature for 30 minutes was as follows :—

(i) In the silica tube—from 900° C. to below 100° C. in about 20 minutes.

(ii) In the tantalum tube—from the highest temperature used to below red heat in 30–60 seconds.

The temperature in the silica tube was measured with a Chromel-Alumel thermocouple while that in the tantalum tube was measured with a disappearing-filament optical pyrometer. The corrections to be added because of the non-black-body conditions were as calculated for an emissivity of 0·35 ($\lambda = 0 \cdot 65$). Several experimental determinations of the melting point of tantalum in similar conditions gave values of 2,550 ± 10° C. (optical temperatures). The application of the calculated corrections was found to give 3,000° C. which was believed to be approximately correct. (Latest published value = 2,996° C.).

The time of heating was 30 minutes in a vacuum of 10^{-4} mm. Hg. pressure. The results of the hardness determinations are shown plotted as a function of temperature in Fig. 4. The amount of deformation of the wires prior to heating is marked on each curve and the vertical lines on the curves represent the scatter of hardness values.

From the figure it will be seen that in the 20 and 40% reduction in area curves, there was an initial small increase in hardness after heating to temperatures between 400° and 500° C., but with greater amounts of

4 Ibid., 1948, 39, 7.

deformation, this increase was not observed. The general effect of deformation was to lower the temperature at which softening was first noticed. After 20% reduction in area, softening commenced between 600° and 650° C., while after 80% reduction in area the softening temperature was 400°–450° C. These annealing temperatures were somewhat lower than was originally expected by comparison with other metals, and with the recrystallisation data. With the more heavily deformed tantalum, the dead soft condition was not reached with 30 minutes heating until temperatures of the order 1,600° C. were used, although with the 20% deformation the lowest hardness was reached at about 1,400° C. Vacuum etching was first perceptible at about 1,750° C., but only became appreciable above about 2,400° C. This observation was in accordance with results obtained during work on the consolidation of tantalum powder[3] when it was found that evaporation of tantalum *in vacuo* became appreciable at 2,450° C.

Conclusion

(i) Tantalum absorbs gases strongly at temperatures of the order 1,800° C., but they can be removed by heating to temperatures above 2,200° C. A study of Fig. 1 indicates that the best gettering temperatures would be 1,700°–1,900° C.

(ii) The absorption of gas by tantalum is accompanied by increases in hardness, electrical resistivity and lattice parameter.

(iii) Gas-hardened tantalum retains its hardness and chemical resistance to attack by many reagents after heating in a high vacuum up to about 1,800° C. The hardening process should be useful for making corrosion and erosion resisting nozzles and dies.

(iv) Some of the mechanical properties of tantalum have been determined and the effect of deformation on these has been studied. Deformation has no effect on the electrical resistivity but it lowers the softening temperature from about 650° to 450° C.

Acknowledgment

This work was performed in the Baillieu Laboratory, University of Melbourne, Australia, under the general direction of Professor J. Neill Greenwood whose counsel the author very gratefully acknowledges.

Painting of Structural Steelwork

Second Interim Report

A SECOND interim report on the painting of structural steelwork has been published by the British Iron and Steel Research Association. The performance of paints for this purpose is being exhaustively investigated by a Joint Technical Panel of the Association's Protective Coatings Sub-Committee. Eleven hundred and seventy-eight specimens have been exposed in an industrial or marine atmosphere at Derby and Brixham respectively to test 268 different paint formulations.

The earliest exposures, to test priming paints, began in October, 1945, and a first interim report was published in December, 1946. In March 1947, further exposures, to test metallic pigments and lead soaps, were begun, and a year later two further series, respectively to test surface preparations and metallic coatings, and bituminous and tar paints. The present report draws some tentative conclusions from the first two series.

Results up to three years' exposure lead to a conclusion that pigment mixtures based on zinc oxide have yielded priming paints giving a performance that is better than average. It will be interesting to see whether this result is confirmed by later observations. In a first series of tests 100 priming paints were used, having various combinations of media and pigments. Twelve media were used, including some of the recent formulations incorporating synthetic resins. Eleven pigments were tested, usually in ternary mixtures consisting of two pigments plus asbestine, used as a standard extender.

In a second series of tests, the objective is to determine the inhibitive character of lead, zinc and aluminium metallic pigments, and to see whether lead and aluminium are as inhibitive as zinc. Individual pigments were mixed on a volume basis in these tests. Aluminium and zinc pigments were mixed with eight different inhibitive pigments, and a varied ratio of inhibitive to metallic pigment was used in the cases of lead sulphate and zinc oxide. Seventy three priming paints, for the preparation of which seven different media were used, were exposed, the painting scheme being completed in each case by a standard finishing coat. Lead soaps were also mixed in 14 priming paints to test their protective qualities. The 11 best paints after 15 months' exposure are listed.

Other Tests

Two series of tests—surface preparation and metallic coatings, and bituminous and tar paints are not far enough advanced to warrant an interim report, exposure having been in progress only since April, 1948. The experimental programmes are fully described.

Methods of preparing specimens before painting for all these tests are detailed and the painting and exposure of the specimens described. It is recognised that variations between painting schemes in paint film thicknesses are of importance, but for immediate practical purpose of the investigation these have been ignored at this stage and it has been thought sufficient to take reasonable steps to ensure that the paints are of good brushing consistency. Can stability tests are being made.

The interim report and reprints are available free of charge from the British Iron and Steel Research Association, 11, Park Lane, London, W.1. Reprints are also available from the B.I.S.R.A. Corrosion Laboratory, 514, Bristol Road, Selly Oak, Birmingham, 29.

SPECIALLOID, LTD. are now in production in their new Leeds factory to which the Sales and Technical Departments have been transferred. The new address is: Specialloid, Ltd., Black Bull Street, Leeds, 10; the Telephone No. being Leeds 31471/7 and the Telegraphic address, Specialoid, Leeds.

The Corrosion of the Austenitic Stainless Steels

Part III—Stress Corrosion

By G. T. Colegate, B.Sc., A.I.M.

In the first two articles of this series, the author outlined the types of corrosive attack to which such steels are subject prior to dealing in more detail with galvanic corrosion, pitting and intergranular corrosion. In the present article, stress corrosion, modified compositions and atmospheric exposure are reviewed.*

Stress Corrosion

THE stress corrosion of stainless steels, unlike ordinary intergranular attack, is a comparatively rare occurrance in practice, and it is not surprising, therefore, that this phenomenon has not received a great deal of study up to the present. Greater interest is, however, now being taken in the stress corrosion of these materials, and work is being carried out in a number of laboratories to establish the precise nature of the attack and to define, with greater precision than has been possible up to the present, the conditions under which it may be expected to occur.

As in most cases of stress corrosion, there is usually very little general attack on the metal beyond the cracking itself; the surface of the crack may be corroded to some extent, but this is very limited.

Our present knowledge of the susceptibility of stainless alloys to stress corrosion is unsatisfactory, scanty and vague. This is partly due to the comparatively small number of cases which are encountered in practice, and partly to the difficulty in deciding what factor or combination of factors, in a given case, was responsible for giving rise to the attack. The latter difficulty is enhanced by the fact that in most of the cases encountered in practice it is possible to point to perhaps a hundred instances of exposure of the same alloy under the same conditions when no stress corrosion has taken place.

Laboratory work has been devoted mainly to the determination of the order of magnitude of the stress necessary to cause failure, and to the investigation of a large number of media suitable for causing accelerated breakdown. Unfortunately, reproducibility of results has not been good, and it is evident that much remains to be done before the correct explanation of the phenomenon can be established.

It might be thought that some relationship would exist between the intergranular corrosion of stainless steels, discussed in a previous article, and stress-corrosion cracking. Although it has been shown that the columbium- and titanium-modified steels, which are resistant to intergranular attack, exhibit rather greater resistance to stress corrosion than do unmodified steels, under the same conditions of exposure, and provided that the stresses applied are not too high, there seems to be little general correlation between the two types of attack. In the first place, although stress corrosion may be intergranular, this is not by any means always the case, and in many instances it is transcrystalline or a combination of both intercrystalline and transcrystalline attack. Moreover, the precautions which can be taken to avoid intergranular corrosion of stainless steels are not necessarily effective in preventing stress-corrosion cracking. For example, steels which have been quenched after a high-temperature treatment are not attacked intergranularly, for the reasons discussed in an earlier article, but such a heat treatment has no effect in reducing susceptibility to stress corrosion. Nor, as far as is known at present, has reduction of the carbon content been found to influence the tendency of the stainless steels to fail in this way. The rather indefinite effect of columbium and titanium additions has been referred to above.

It is the transcrystalline manifestation of stress corrosion which is, at the same time, the most frequently encountered and the most difficult to explain. In practice, it is often extremely difficult to decide, in a case of intercrystalline attack, whether stress has played any part at all in the failure or whether the failure is entirely due to chromium depletion near the grain boundaries, although, if the exact history of the steel is known, it should be possible to rule out the latter type of attack if the metal has received the correct heat treatment, etc. Some authorities consider that, even when stress does play a part in the attack, the impoverishment in chromium near the grain boundaries has a lot to do with determining the steel's susceptibility to attack.

Corrosive Media Responsible

Stress-corrosion cracking of stainless steel does not occur in all potentially corrosive media; in fact, it occurs in relatively few. Several chlorides have been shown to cause attack, though it would certainly be incorrect to assert that chlorides are indispensible; in fact, many of the failures reported to have taken place in practice have occurred in the absence of chlorides, or, for that matter, of any material which would normally be regarded as corrosive towards stainless steels. Conversely, not all chlorides cause failure. This is all the more remarkable in that there is a total difference in behaviour between what are chemically closely related chlorides. For example, Franks, Binder and Brown[1] showed that cold-rolled strip, containing 18% chromium and 6% nickel, cracked in both a 10% and a 30% solution of lithium chloride at boiling point, whereas, in sodium chloride solutions of the same strengths and also at boiling point, the only attack which occurred was slight pitting. Among other chloride solutions, all at boiling point, which were found to cause attack, were

* *Metallurgia*, January, 1950, **41**, 243, 147–150.
Metallurgia, March, 1950, **41**, 245, 259-262

1 A.S.T.M.-A.I.M.E. Symposium on Stress-Corrosion Cracking of Metals. 1945, p. 411.

ammonium chloride, magnesium chloride, zinc chloride and calcium chloride. The chlorides of tin, barium, mercury, chromium, nickel and strontium failed to produce stress corrosion. In the same set of experiments, potassium fluoride, sodium bromide, potassium bromide, sodium fluoride, and 65% nitric acid all failed to produce cracking. Scheil[2] states that aqueous acid chloride solutions are the most active media in producing transcrystalline cracking, but that neither the chloride ion, nor the acid environment is a necessary condition, since failures have been recorded in acid sulphite cooking liquors, in which the presence of appreciable quantities of chlorides was unlikely, and in a caustic soda solution at 350° C. under pressure. There have, moreover, been many cases reported from service in which the failure has taken place in the presence of what must have been more or less pure water vapour, and at temperatures no higher than 100° C. The writer saw one such instance in a water-heating device used in a canteen. The cracking had started from a hole which had been drilled, or punched, in 18 : 8 stainless-steel sheet, and which was exposed to water vapour at about 100° C. In this instance cracking was entirely transcrystalline, there being no trace of any intercrystalline attack. It was not possible to establish exactly the length of time that the equipment had been in service, but it was of the order of six months.

Another point which it is extremely difficult to explain satisfactorily with our present knowledge, is an observation by Scheil[2] that stress-corrosion test specimens with surfaces roughened by pickling are much more resistant to stress-corrosion cracking than specimens of the same metal, exposed under the same conditions, but with a polished surface.

It has been established that both residual and applied stress will lead to corrosion cracking in stainless steels, though it has not so far been possible to establish with any degree of accuracy the magnitude of the stress required to cause cracking under any particular conditions of exposure. However, as a rough approximation, steels subject to a stress of more than 10,000 lb./sq. in. may be expected to be susceptible to attack. This is, of course, a very low stress, and one which may easily be reached as a result of forming operations during fabrication, or of expansion and contraction, etc., during use.

Susceptibility Test

The most generally used solution for testing susceptibility of austenitic stainless steels to stress corrosion is one developed by Scheil[2] and containing 42% magnesium chloride. This is used boiling and the time of immersion may be several hundred hours. This chloride solution is found to cause cracking in most types of susceptible austenitic steels, but many of the other chloride solutions mentioned above will only cause cracking in some of the steels. Until more cases of stress-corrosion cracking in service have been studied, and until more is understood about the mechanism of the attack, it will not be possible to relate the results obtained in the magnesium chloride test with practice in the same way, for example, as the mercurous nitrate test, used in detecting susceptibility of brasses to season cracking, can be related to practice. However, the magnesium chloride test is the best so far developed and appears to be reasonably satisfactory.

The time required to cause cracking, in specimens exposed to the magnesium chloride test solution, varies very considerably with the composition of the alloy. The same applies to exposure to other corroding media.

It has been established that the magnesium chloride test will detect susceptibility to transcrystalline stress cracking, even in those steels which are known to be sensitive to ordinary intercrystalline attack. Under the conditions of exposure no intercrystalline attack is produced by this reagent in such a steel.

Effect of Stress

There are a number of cases on record of cracking starting at points of localised stress such as a punched hole, or a stamped indentification number. Other causes of stress which have been known to lead to cracking are the cold straightening of tubes, etc., after annealing, and stresses caused by welding. Deep drawing is particularly liable to render stainless steels susceptible to stress-corrosion cracking ; ordinary cold rolling of sheet, of course, may also render an alloy liable to attack. Some authorities take the view that failure may start at stresses below 10,000 lb./sq. in. even as low as 3,000 lb./sq. in., and this may well be the case in environments which are particularly favourable to this type of attack, though it is doubtful whether, in the less aggressive environments, stresses as low as this would be dangerous. At present, of course, it is not possible to define, with any confidence, which environments can be described as particularly aggressive.

An interesting point in connection with this type of stress-corrosion cracking is that failure invariably begins at points where the metal is in tension. This applies in the case of both applied and residual stress. Even if there is an area of higher stress on that part of the metal which is in compression, the cracking does not commence there. This is another point on which further work will be necessary before a satisfactory explanation can be established.

In material such as tube, sheet, etc., it is possible to overcome any tendency to stress corrosion by using a stress-relieving anneal, but it is not always easy to use such a method in the case of fabricated equipment. In such cases, there is no known cure for the trouble. If a stress-relieving anneal is used the temperature should not be lower than 850° C. ; temperatures appreciably lower than this produce uncertain results.

Virtually all the austenitic stainless steels are liable to suffer stress corrosion, but there is definite evidence that the higher the nickel content of the alloy the more resistant is it likely to be. In most accelerated tests using magnesium chloride it is possible, ultimately, to bring about cracking, but the steels with the higher nickel contents take much longer to develop cracks than those which are lower in nickel. Generally speaking, there is a considerable improvement in this respect with steels having a nickel content above about 7%.

At least one set of experiments is on record in which stressed stainless-steel specimens were exposed to a marine atmosphere instead of to corrodants, such as magnesium chloride solution, which gave accelerated attack. In the case in question a number of stressed specimens of an austenitic steel containing 17% chromium and 7% nickel were exposed for 8,600 hours, near the sea coast, and after that time none of them had failed by stress cracking. Other, unspecified stainless steels were also tested with the same result.

Modified Austenitic Stainless Steels

Many modifications have been made to straight austenitic chromium-nickel steels with a view to

2 Corrosion Handbook. (Wiley), 1948, p. 174.

improving their corrosion resistance. The best-known, of course, are the additions of titanium and columbium for preventing intergranular attack. Besides these, however, various additions have been made with a view to improving general corrosion resistance. Some of the more important of these are discussed below. In many cases, the addition serves more than one purpose, modifying, for example, the mechanical properties of the alloys, either at normal or at elevated temperatures, or improving resistance to high-temperature oxidation, a subject outside the scope of the present article.

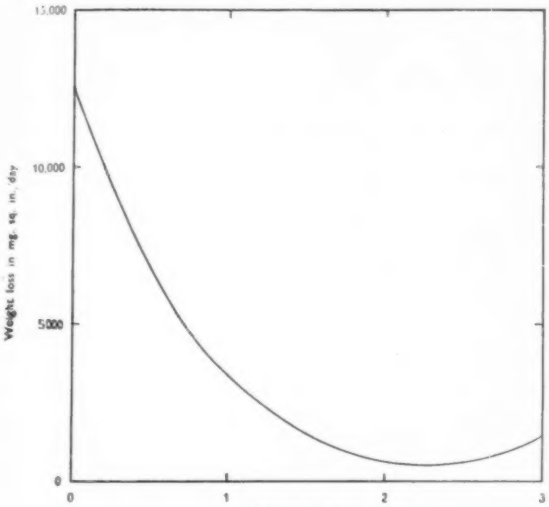


Fig. 1.—Effect of copper on the loss of weight of 18 : 8 stainless steel in boiling 10% sulphuric acid.

Molybdenum.—This is one of the most important additions made to this type of steel, and is probably the one which gives the best all-round results. Usually added in amounts varying from 2 to 4%, it improves resistance to intergranular corrosion, a point which is discussed elsewhere, and also resistance to pitting. It is in the latter connection that molybdenum is probably most valuable. It cannot be claimed that molybdenum additions are completely effective in suppressing pitting under all conditions, but the presence of the element has a very marked effect. For example, resistance to pitting is greatly enhanced in chloride solutions; a ferric chloride solution pits straight 18 : 8 chromium-nickel steel but the attack is far less pronounced if molybdenum is present. Molybdenum-bearing steels also show less tendency to pit in the sulphite solutions used in the paper industry and in weak acid solutions.

Molybdenum also reduces the likelihood of crevice corrosion in austenitic stainless steels. In steels containing the amount of molybdenum mentioned above, the tendency to crevice corrosion is about halved, compared with those without the addition.

Resistance to various chemical solutions is also improved by the addition of a few per cent of molybdenum to these alloys. Chief among these is sulphurous acid, though various weak organic acids such as acetic, oxalic and formic give appreciably less attack on molybdenum-bearing steels than on straight chromium-nickel ones. The same also applies to hydrochloric and sulphuric acids.

On the other hand, molybdenum additions tend to reduce the resistance of these steels to strongly oxidising liquids.

Silicon.—This element reduces the resistance of austenitic stainless steels to attack by nitric acid but improves their resistance to hydrochloric, sulphuric and other acids. Besides this, silicon has very little effect on the general corrosion properties of this type of steel, except, of course, on its resistance to high-temperature oxidation.

Copper.—This is an element which has been used commercially as an addition to austenitic stainless steels for the purpose of improving corrosion resistance, the amounts used varying between 2 and 6%. The presence of copper improves resistance to chlorides, including dilute hydrochloric acid and brine. It is also claimed that the higher amounts of copper improve resistance to scaling at high temperatures.

Additions of copper to austenitic stainless steels have been successfully used to increase their resistance, under certain conditions of exposure, to corrosion by sulphuric acid. The presence of small percentages of copper greatly reduces attack by this acid, the optimum effect being at about 2% copper. Fig. 1[3] illustrates this point very clearly. It is not claimed that such copper additions are of benefit under all conditions of exposure; for example, there is no improvement in the behaviour of these steels in contact with acetic acid or nitric acid.

Copper does not improve the resistance of stainless steels to intergranular attack. On the other hand, Cone[4] has shown that the presence of 1½% each of copper and molybdenum improves the resistance of the 18 : 8 steels to many corrosive media.

Selenium and Sulphur.—Both these elements have been used as additions to austenitic stainless steels on a commercial scale. As far as is known, sulphur has very little effect on the corrosion resistance when present in amounts up to about 0·40%, the amount of sulphur sometimes added to confer free-machining properties on these steels. Selenium, on the other hand, does reduce corrosion resistance slightly when present in amounts of the same order, though the reduction is so small as to have little practical significance. There is, however, a certain amount of evidence that selenium additions tend to increase the tendency of these steels to pit, especially in solutions such as ferric chloride. The effect is less pronounced in sea water.

Several other elements have been added to stainless steels of the type under discussion, mainly with a view to improving their mechanical properties, but very little information is available on their effect on corrosion resistance.

Atmospheric Exposure

No serious corrosion takes place on the austenitic stainless steels when exposed to any atmosphere, even of the marine or heavy industrial type. The most that occurs is surface discolouration, very light surface rusting, and very shallow pitting. In rural atmospheres, and often in marine and urban ones too, there is little noticeable loss of brightness, especially on vertical surfaces. Discolouration may occur in the more severe industrial atmospheres and is almost entirely due to the sulphur, though of course, and particularly on horizontal surfaces, dust deposits and soot will also detract from the appearance of stainless steel exposed in such atmos-

3 "Copper as an Alloying Element in Steel and Cast Iron." Lorig and Adams. (McGraw Hill), 1948, p. 117.
4 *Iron Age.* Feb. 8th, 1934, **133**, p. 31.

pheres. It is largely under such deposits that pitting takes place, although this is also liable to occur as a result of contact corrosion, and is particularly noticeable in such articles as wire gauze, at the points where the wires cross. The severity of the pitting naturally depends on the conditions of exposure, but it seldom amounts to anything more than surface roughness. A great deal, if not all, of the corrosion that takes place on stainless steel in the atmosphere, can be prevented by frequent washing down of the surface.

Many tests carried out on stainless steels of the austenitic type, in urban and rural atmospheres, have shown no measurable loss in weight after several years exposure, while in the more corrosive atmospheres, weight losses of the order of 0·05 mg./sq. dm./day are the most that have been found.

It is of interest to note that in the more corrosive atmospheres, particularly those containing sulphurous gases, the presence of molybdenum in the steel appreciably reduces the tendency to suffer deterioration.

Costing and Modern Accounting Methods in the Metal Industries

V.—Computing and Recording Depreciation

By S. Howard Withey, F.Com.A.

The "straightline" and "percentage" methods for computing the depreciation of plant and equipment are discussed and the advantages of the latter are demonstrated in cases where the increasing age of the plant is accompanied by an appreciable increase in the maintenance costs.

THE present labour situation emphasises the desirability of making the utmost use of mechanisation, the first cost of acquiring and installing machinery and plant being posted direct to the debit side of an account opened in the private ledger, to which should be added the expenditure incurred in effecting adjustments or in carrying out repairs needed to render equipment efficient for a specific purpose. In all cases where expenditure has the effect of increasing the value of the profit-earning installations, the amount involved should be debited to the asset account and then subjected to periodical deductions to cover depreciation. When a productive asset is displaced by another possessing improved efficiency at a lower cost of operation, the book value of the old asset should be written off by means of a direct transfer to profit and loss.

"Straightline" Computation

When costs of upkeep do not vary materially as between one year or operating period and another, an equal proportion of the original cost of the equipment should be charged each year and, in order to indicate the method of applying this "straightline" computation, a case may be cited in which the furnaces, presses, handling plant and tools employed by a firm specialising in various types of heat treatment were shown in the books at a value of £120,000 (in round figures) as at 31st December, 1948. It was estimated that the realisable value at the end of another five years would be £40,000, and as the firm had considerable liquid resources and was in a position to re-equip and modernise its plant without having to seek special banking facilities, a scheme of development was evolved, based on prevailing prices. In January, 1949, additional units of plant and a variety of tools were purchased from a firm in the Midlands at a cost of £50,000, this figure being entered in the purchase journal and extended into a "capital outlay" column. These additions were expected to be worth about £30,000 after ten years' service, and for the purpose of incorporating a standard figure for depreciation in the production costs over the next five years the following computations were approved :—

COMPUTATION OF DEPRECIATION

FURNACES, PRESSES, HANDLING PLANT AND TOOLS

	£
(*a*) *Original*—	
One-fifth of £80,000 (viz :—value as at December, 1948, *less* estimated value five years hence) ..	16,000
(*b*) *Additions*—	
One-tenth of £20,000 (viz :—capital cost as at January, 1949, *less* estimated value 10 years hence)	2,000
Annual Depreciation	£18,000

At the end of five years, the asset account will show the following figures :—

Debit FURNACES AND PLANT, ETC., ACCOUNT Credit

		£			£
1948 Dec. 31.	To Balance brought down	120,000	1949 Dec. 31.	By Depreciation written off ..	18,000
1949 Jan. 1.	To Additions	50,000	Dec. 31.	By Balance carried down	152,000
		£170,000			£170,000
1950 Jan. 1.	To Balance brought down	152,000	1950 Dec. 31.	By Depreciation written off ..	18,000
			Dec. 31.	By Balance carried down	134,000
		£152,000			£152,000
1951 Jan. 1	To Balance brought down	134,000	1951 Dec. 31.	By Depreciation written off ..	18,000
			Dec. 31.	By Balance carried down	116,000
		£134,000			£134,000
1952 Jan. 1.	To Balance brought down	116,000	1952 Dec. 31.	By Depreciation written off ..	18,000
			Dec. 31.	By Balance carried down	98,000
		£116,000			£116,000
1953 Jan. 1.	To Balance brought down	98,000	1953 Dec. 31.	By Depreciation written off ..	18,000
			Dec. 31.	By Balance carried down	80,000
		£98,000			£98,000
1954 Jan. 1.	To Balance brought down	£80,000			

The debit balance of £80,000 shown in the account as at the end of December, 1953, will represent the original assets worth £40,000 and the additions having

a value of £40,000. In this case, the annual cost of repairs, testing, cleaning, overhauling and adjusting was shown to be relatively low, but when machinery is in almost continuous operation the wear and tear on the moving parts and auxiliaries is, naturally, much greater than when productive assets are not subjected to excessive use, so that it is true to say that, while some tools and appliances do not always realise their expected length of service or useful life, many units of machinery give satisfactory service over longer periods than originally anticipated. Much depends on maintenance and skill in manipulation, and with "make-do-and-mend" the order of the day it is not surprising that the audited accounts of metal manufacturers and traders show a definite tendency for repairs and renewals to increase each year with the gradual decline in asset values.

"Percentage" Computation

The advantages of applying the "percentage" method of computation whereby the book value of a group of machines is subjected to a percentage deduction each year, based on diminishing value, was emphasised in a case where the plant and machinery employed by a metal producing company in the North had a balance sheet value of £144,000 as at December, 1948. A number of large contracts had been entered into and, having regard to the nature of the operations to be undertaken, the company's planning department was instructed to prepare a maintenance budget covering a period of ten years. This showed progressive increases from £18,000 for the first year to £32,400 for the tenth year, as follows (in round figures) :—

BUDGET FOR MAINTENANCE OF FIXED PLANT

	£
1st Year	18,000
2nd Year	20,000
3rd Year	22,000
4th Year	24,000
5th Year	26,000
6th Year	27,400
7th Year	28,400
8th Year	30,000
9th Year	31,200
10th Year	32,400

In March, 1949, additional plant was acquired at a total cost of £54,000 and it was anticipated that the original assets of £144,000 would realise something like £50,000 if sold in 10 years' time. In July, 1949, further plant was installed at a cost of £68,000, and on the advice of the engineers it was decided to spread this capital outlay as equitably as possible over the budget period on the assumption that this equipment could be transferred to a subsidiary company for £22,000 after 13 years' service. It was also agreed that the plant acquired in March, 1949, would possess a value of about one quarter of its original capital cost at the end of 15 years, and draft accounts were required giving effect to the above set of circumstances.

In order to equalise the combined charge for depreciation and upkeep, it was realised that a percentage would have to be written off the book values each year; it was also realised that there would be a material difference between a percentage deduction from the first or original capital cost and the same percentage deduction when applied to the reduced book value. The rates to be applied were ascertained by referring to a depreciation table.

The table shows the percentage of the original or existing value which would be extinguished over varying periods at varying rates; for example, in the case of the plant valued at £144,000 and expected to be worth £50,000 after 10 years, an amount equal to slightly more than 65% of the book value would have to be written off during the period, and reference to the table shows the percentage rate as 10%. Plant costing £68,000 and expected to possess a book value of £22,000 at the end of 13 years would have 67% of its value written off, the rate to be applied being 8%. The depreciation computations for 10 years were, therefore, presented in the form indicated below :—

TABLE I—PLANT DEPRECIATION TABLE

Years	7%	8%	9%	10%
1	7·00	8·00	9·00	10·00
2	13·51	15·36	17·19	19·00
3	19·56	22·13	24·64	27·10
4	25·19	28·36	31·42	34·39
5	30·43	34·09	37·59	40·95
6	35·29	39·36	43·21	46·86
7	39·84	44·21	48·32	52·17
8	44·03	48·67	52·97	56·95
9	47·97	52·78	57·20	61·26
10	51·61	56·56	61·06	65·13
11	55·00	60·03	64·56	68·62
12	58·15	63·23	67·75	71·76
13	61·08	66·17	70·65	74·58
14	63·80	68·87	73·29	77·12
15	66·33	71·37	75·70	79·41
16	68·69	73·66	77·88	81·47
17	70·88	75·77	79·87	83·32
18	72·92	77·70	81·68	84·99
19	74·81	79·48	83·33	86·49
20	76·58	81·12	84·83	87·84
21	78·22	82·62	86·20	89·06
22	79·74	84·02	87·44	90·15
23	81·16	85·30	88·57	91·44
24	82·48	86·48	89·60	92·02
25	83·71	87·56	90·53	92·82

DEPRECIATION COMPUTATIONS

	£
1st Year	
10% of £144,000 (i.e., existing book value)	14,400
9% of £54,000 (i.e., capital cost, March, 1949)	4,860
8% of £68,000 (i.e., capital cost, July, 1949)	5,440
Depreciation	£24,700
2nd Year	
10% of £129,600 (i.e., £144,000 *less* £14,400)	12,960
9% of £49,140 (i.e., £54,000 *less* £4,860)	4,422
8% of £62,560 (i.e., £68,000 *less* £5,440)	5,004
Depreciation	£22,386
3rd Year	
10% of £116,640 (i.e., £129,600 *less* £12,960)	11,664
9% of £44,718 (i.e., £49,140 *less* £4,422)	4,024
8% of £57,556 (i.e., £62,560 *less* £5,004)	4,604
Depreciation	£20,292
4th Year	
10% of £104,976 (i.e., £116,640 *less* £11,664)	10,498
9% of £40,694 (i.e., £44,718 *less* £4,024)	3,662
8% of £52,952 (i.e., £57,556 *less* £4,604)	4,236
Depreciation	£18,396
5th Year	
10% of £94,478 (i.e., £104,976 *less* £10,498)	9,448
9% of £37,032 (i.e., £40,694 *less* £3,662)	3,332
8% of £48,716 (i.e., £52,952 *less* £4,236)	3,738
Depreciation	£16,518
6th Year	
10% of £85,030 (i.e., £94.478 *less* £9,448)	8,504
9% of £33,700 (i.e., £37,032 *less* £3,332)	3,034
8% of £44,978 (i.e., £48,716 *less* £3,738)	3,598
Depreciation	£15,136
7th Year	
10% of £76,526 (i.e., £85,030 *less* £8,504)	7,652
9% of £30,666 (i.e., £33,700 *less* £3,034)	2,760
8% of £41,380 (i.e., £44,978 *less* £3,598)	3,310
Depreciation	£13,722
8th Year	
10% of £68,874 (i.e., £76,526 *less* £7,652)	6,888
9% of £27,906 (i.e., £30,666 *less* £2,760)	2,512
8% of £38,070 (i.e., £41,380 *less* £3,310)	3,046
Depreciation	£12,446
9th Year	
10% of £61,986 (i.e., £68,874 *less* £6,888)	6,198
9% of £25,394 (i.e., £27,906 *less* £2,512)	2,286
8% of £35,024 (i.e., £38,070 *less* £3,046)	2,802
Depreciation	£11,286
10th Year	
10% of £55,788 (i.e., £61,986 *less* £6,198)	5,578
9% of £23,108 (i.e., £25,394 *less* £2,286)	2,080
8% of £32,222 (i.e., £35,024 *less* £2,802)	2,578
Depreciation	£10,236

The debit balance of £100,882 shown in the company's plant and machinery account at the end of the period will be made up of £50,210, being the book value of the original equipment ; £21,028 being the value of the plant acquired in March, 1949 ; and £29,644 being the value of additions installed in July, 1949. It should be noted that if the "straightline" method is applied to the above set of circumstances for the purpose of reducing the book value from £266,000 to £100,882 it would be necessary to write off one tenth of £165,118 each year, and the combined charge for depreciation and maintenance would be as shown below :—

	Depreciation £	Maintenance £	Total £
1st Year	16,512	18,000	34,512
2nd Year	16,512	20,000	36,512
3rd Year	16,512	22,000	38,512
4th Year	16,512	24,000	40,512
5th Year	16,512	26,000	42,512
6th Year	16,512	27,400	43,912
7th Year	16,512	28,400	44,912
8th Year	16,512	30,000	46,512
9th Year	16,512	31,200	47,712
10th Year	16,512	32,400	48,912
	£165,120	£259,400	£424,520

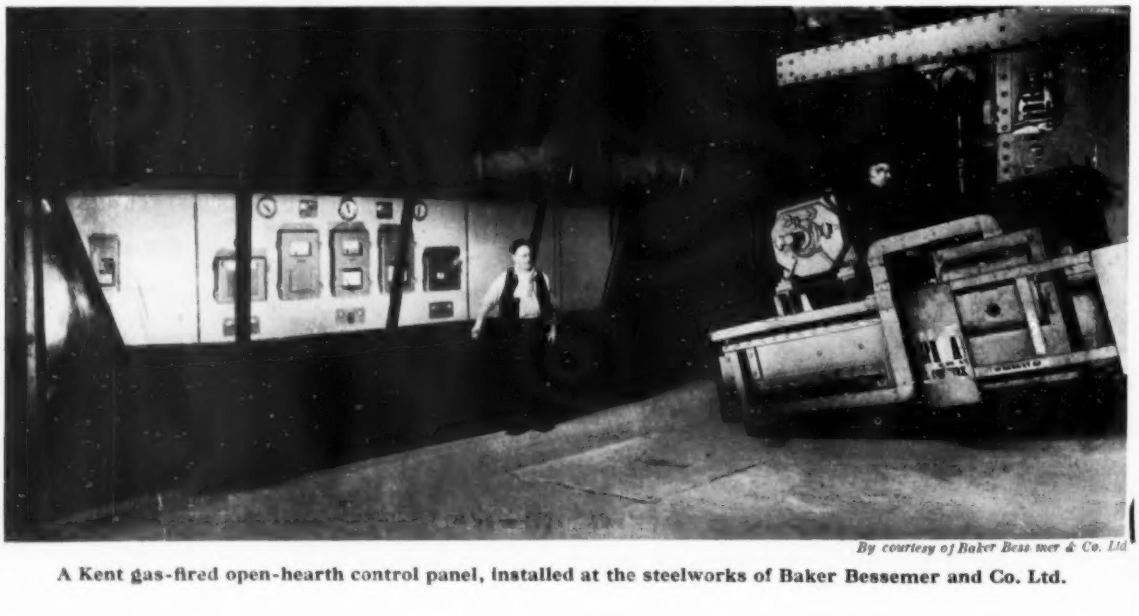
In other words, the annual burden would increase from £34,512 in the first year to £48,912 in the tenth year, whereas by applying the "percentage" method the burden will be spread much more evenly over the budget period :—

	Depreciation £	Maintenance £	Total £
1st Year	24,700	18,000	42,700
2nd Year	22,386	20,000	42,386
3rd Year	20,292	22,000	42,292
4th Year	18,396	24,000	42,396
5th Year	16,518	26,000	42,518
6th Year	15,136	27,400	42,536
7th Year	13,722	28,400	42,122
8th Year	12.446	30,000	42,446
9th Year	11,286	31,200	42,486
10th Year	10,236	32,400	42,636
	£165,118	£259,400	£424,518

It is clear, therefore, that in all cases where the cost of upkeep is expanding each year, a more uniform figure for inclusion in costs can be arrived at by percentage computations based on reduced book values. Industry is expected to limit the amount of capital expenditure as part of the all-out effort to close the import-export gap, and for some years the factor of repairs to plant is likely to demand constant consideration on the part of directors, executives and managers. For purposes of modernisation and development, however, considerable amounts will have to be raised from time to time and when computing the annual charge for inclusion in costs another important factor is interest on capital. The next article will show how this may be provided for, and will also indicate the method of building up a sinking fund for plant replacement.

Control of Open Hearth Furnaces

THE further increase in the production of steel in British steelworks recently reported is due in no small measure to the increasing use of complete equipment not only to measure but to effect automatic control of the various processes involved. In open-hearth furnace operation the object is to obtain the highest rate of steel production consistent with good refractory life and fuel economy. The life of the roof refractories is dependent on the roof temperature, which can be effectively measured to provide a continuous record and to effect practical precision roof temperature control with correctly regulated fuel supply. This allows the furnace to be run at the highest safe temperature, eliminating any temperature drop after firing reversals and the attainment of the highest melting efficiency, with insurance against damage to refractories. Other major factors in obtaining maximum production are combustion efficiency and correct furnace pressure, both of which involve measurement and control. A particularly useful publication describing typical open-hearth furnace control schemes, both for oil- and gas-fired furnaces, is available from George Kent, Ltd., Luton, Bedfordshire.



By courtesy of Baker Bessemer & Co. Ltd

A Kent gas-fired open-hearth control panel, installed at the steelworks of Baker Bessemer and Co. Ltd.

The Institute of Metals

Annual General Meeting held in London

A very attractive programme had been arranged for this meeting, which showed a reasonable balance between the science of metal physics and the problems of industrial metallurgy, and the interest taken in the proceedings, particularly in the Symposium on metallurgical aspects of the hot rolling of non-ferrous metals and alloys, showed that efforts made to obtain this balance were appreciated. Considerable discussion took place on the Symposium and various papers and here only a very brief report can be given of the early proceedings.

THE Annual General Meeting of the above Institute, which was held in London on March 29th to 31st inclusive, was well supported. A very full but admirable programme had been arranged in which the business of the Institute occupied a relatively small part, much of the meeting being concerned with the discussion of some aspects of metal physics and with problems of industrial metallurgy, although social activities were not overlooked. The initial business meeting was held at the Café Royal, Regent Street, W.1, with the President, Sir Arthur Smout, J.P. in the Chair, who, at the outset, extended a hearty welcome to all attending the meeting, particularly to overseas visitors. Quite a strong contingent of members and friends from overseas were present, it was impossible for the President to name all these ladies and gentlemen, but referred specially to Professor Portevin, who has rendered great service to metallurgical education in France, Dr. R. A. Wilkins, the Institute's honorary correspondent in U.S.A., M. Jean Matter, one of the Institute's honorary correspondents in France, Professor Forward, Head of the Department of Mining and Metallurgy of the University of Columbia, and Mlle. Sigwalt, whom the President referred to as that great little lady who organised the Institute's Paris visit and who rendered to the allied cause such distinguished service in the Underground Movement during the war, service so distinguished that she is one of the very few who wear the coveted decoration which His Majesty awarded to subjects not of British nationality for bravery and devotion to the Allied cause.

Report of Council

Before moving formally the adoption of the Report of the Council, published in the February issue of the Institute's journal, on which he made no comment, apart from mentioning that the document marks considerable progress, the President stated that, thanks to the generosity of a donor firm, the Council had received a sum of money sufficient to enable it to found a Medal in memory of that brilliant English metallurgist, Walter Rosenhain. The Medal will be awarded annually for work of exceptional merit in the field of physical metallurgy, and will, suggested the President, form a worthy memorial to a man who did so much to place the art of metallurgy on a scientific basis.

Dr. F. A. Fox seconded the motion admirably in which he suggested that the Institute caters extremely well both for the social side as well as for the strictly professional side. On looking at the Report, he thought there was no ground whatever for worry by any of the Institute's officials, honorary or permanent. The Institute is providing exceptionally good services and, during the period 1949, it has gone from strength to strength.

Election of Officers

The Secretary, Lt.-Col. S. C. Guillan, announced the names of members elected to fill vacancies on the Council for the year 1950–51, as follows :—

President : Mr. H. S. Tasker, B.A.

Vice-Presidents : Professor H. O'Neill, D.Sc., D.Met., and Professor F. C. Thompson, D.Met., M.Sc.

Ordinary Members of Council : Mr. G. L. Bailey, M.Sc. ; Mr. Harry Davies ; Mr. E. H. Jones ; Dr. L. B. Pfeil, O.B.E., A.R.S.M. ; and Professor G. V. Raynor, D.Sc., D.Phil., M.A. As was announced at the Paris meeting the Council has elected Professor A. J. Murphy, M.Sc., to be Senior Vice-President for the year 1950–51.

W. H. A. Robertson Medal

The President announced the first award of the W. H. A. Robertson Medal made jointly to Mr. W. J. Thomas and Mr. W. A. Fowler for their paper on " Some Technical Problems Influencing Production Economy in the Rolling of Aluminium." It was exactly the type of paper he had in mind when he referred, in his Presidential Address two years ago, to the need for papers dealing with industrial problems of metallurgy. He felt sure it was also the type of paper which the donor of the medal, Mr. Robertson, had in mind when he founded the medal and premium. Mr. Robertson could claim to be the doyen of the Institute ; it was due to a suggestion he made over 40 years ago that this Institute was founded, and the President expressed pleasure that Mr. Robertson was at the present meeting.

In the absence of Mr. Fowler, who was on the sick list, both medals were presented to Mr. Thomas. In expressing appreciation of the honour conferred on Mr. Fowler and himself, Mr. Thomas said the paper covered most of the features they had under review each day in trying to improve rolled products. In that work they had the collaboration of quite a number of their colleagues and their assistance in the wide range of subjects covered, and regard themselves as joint custodians of all that has been done.

New President

Following the presentation of the Robertson Medal, Sir Arthur inducted the new President, Mr. H. S. Tasker, into the Chair. In doing so he said that Mr. Tasker possessed unique qualifications for the office ; his work on the administrative side of the non-ferrous metals industry is well known in this country and in the Dominions. He has done much in the metallurgical educational field and in raising the general status of the profession of metallurgy.

Mr. Tasker expressed his thanks in a few well chosen words and called upon Mr. G. L. Bailey to propose a vote of thanks to Sir Arthur Smout for his services as

President for the years 1948–49 and 1949–50. Mr. Bailey said that Sir Arthur had served the Institute with conspicuous ability and with his usual energy and enthusiasm and it gave him great pleasure in proposing that a hearty vote of thanks be accorded to Sir Arthur Smout. This was ably seconded by Professor A. J. Murphy and carried with acclamation.

Award of the Institutes' Platinum Medal

At a luncheon at the Café Royal, following the morning meeting, the President presented the 1950 Platinum Medal to the distinguished French metallurgist, Professor Albert Portevin, in recognition of his eminent services to the science and practice of non-ferrous metallurgy. The French Ambassador was present at this ceremony.

Professor Portevin, who is a Commandeur de la Légion d'Honneur, a Commandeur de l'Ordre de la Couronne de chêne de Luxembourg, and a Membre de l'Institut de France, was trained as an engineer. He was director of the laboratories of the de Dion-Bouton motor works from 1905–1912; lecturer and later Professor at the Ecole Centrale des Arts et Manufactures from 1912–1925; and was appointed Professor at the Ecole Supérieure de Soudure Autogène (Paris) in 1931. Most of his work has been on physical metallurgy, particularly of steels.

In making the presentation the President said the wide international range of the membership and associations of the Institute of Metals is naturally and rightly regarded with pride. It is, therefore, particularly fitting that this year the Council decided to confer its highest honour on a great French metallurgist, Professor Albert Portevin. The many honours received by him testify to the value of his work, and now the Institute of Metals adds its own tribute to a great metallurgist and a great Frenchman.

In accepting the award, Professor Portevin said that the more than helpful colleagues he had found amongst members of the Institute have played an important part towards the achievement of this unique distinction, by creating a most cordial atmosphere within the very Council—by which he now benefits. He referred to many former Presidents of the Institute, who he regarded as his friends. The need for the setting up of a French metallurgical organisation, with a view to facilitating intercourse between the two countries was suggested in a letter dated April 5th, 1940, signed by the Presidents of the two great English metallurgical institutes. Although the war interrupted this project, it has been taken up and now he could say that the initial foundation of the French Society of Metallurgy came directly from these Institutes, which are, in a way, its sponsors. Professor Portevin expressed his regrets for speaking in French rather than English, his speech, however, was interpreted by Professor A. J. Murphy.

Technical Sessions

The meeting was transferred to the Institution of Mechanical Engineers, following the luncheon, to commence the discussion of several technical papers which formed part of the programme. The first paper to be discussed was by Dr. E. Scheuer who dealt with modern billet casting, with special reference to the solidification process; the next three papers were discussed together, they included grain refinement of aluminium and its alloys by small additions of other elements by Myriam D. Eborall; the mechanism of grain refinement of sand castings in aluminium alloys by A. Cibula; and the effect of grain size on the tensile properties of high-strength cast aluminium alloys by A. Cibula and R. W. Ruddle. All the papers were discussed at considerable length and it is only possible here to present some of the main points raised.

MODERN BILLET CASTING, WITH SPECIAL REFERENCE TO THE SOLIDIFICATION PROCESS

By E. Scheuer, Dr. phil. nat.

BILLET casting lends itself more readily to detailed theoretical and mechanical study than does the production of other castings, because simple geometrical shapes have to be produced in large quantities; considerable expenditure on research and equipment to produce them is, therefore, justified in order that they may be of uniformly high and consistent quality. This paper is mainly concerned with this question of quality and various processes of billet casting are discussed with this end in view.

The characteristic feature of the continuous-casting process, as opposed to the conventional billet-casting processes, is the stationary condition of the liquid part of the billet and of the solidification zone during the casting operation. The method is the outcome of a long and varied development, the main goals of which have been to secure improvement in production economy and in quality of the billet.

The requirements of an ideal billet-casting process are outlined on the basis of the structure of an ideal billet. Conventional billet-casting methods fail to meet these requirements in many respects, and developments aiming at overcoming these deficiencies are reviewed. The latest of them is the continuous-casting process, which comes much nearer to satisfying the requirements of the ideal casting process than the methods previously in use. In the aluminium industry it has, since the war, become by far the most popular casting process.

Improvements are still needed in:

(*a*) Elimination of radial internal stresses which can produce hot tears and cracking of finished billets.

(*b*) Application of the method to high-melting-point alloys (copper alloys, steels, etc.).

(*c*) Development of the continuous strip-casting process to a point where it can become a popular production method.

Discussion

Dr. Scheuer, introducing his paper, referred to correspondence from Mr. Irving Rossi and Dr. Francis C. Frary, who supplemented and partly corrected his report. The former referred to the author's somewhat pessimistic view of the application of the process to copper alloys and stated that he had built about 20 casting machines in the United States. These were working on aluminium, copper, brass and steel and something like 2,000,000 tons of brass billets had been produced by the solidification process. The production rate—a little more than 8 tons per hour on one machine—was very high. He also stated that he believed the resistance of the mould to high-temperature melting alloys was less of a problem than would appear from the paper: he had cast steel in moulds made from copper and had found no difficulty.

Dr. Francis C. Frary had written to say he thought the Hazelett process which worked with rollers in order to produce a cast strip had been disappointing in the practical tests in the United States, and he did not think there was any industrial merit in it in its present form. He also mentioned that the Aluminium Company of America had already switched over all their high-strength aluminium billets to the continuous-casting process several years before the war, and he claimed that they were probably the first people to use this process on an industrial scale.

Mr. W. A. Baker thought the most striking feature of the popular short-sleeve mould process was its apparent simplicity. However, it was clear from the paper that even in this apparently simple process there were many points of detail which must be closely controlled. One of the major problems was that of high internal stress in the high-strength light alloys cast by this method. These stresses might be minimised in two diametrically opposite ways: by extracting heat from the solidified metal in one direction parallel to the axes, in which case the lateral temperature gradients would be reduced to a minimum and the thermal stress would consequently be eliminated; the alternative was to extract the heat from the ingot as it emerged from the mould and to allow the heat of the core of the lower part of the ingot to be transmitted to the outer layers.

Dr. W. M. Doyle said that modern continuous-casting process was now generally accepted as far as light alloys were concerned. It must be admitted, however, that very high-strength alloys of the D.T.D. 363A type or certain compositions conforming to that specification of binary alloys containing over 7% magnesium were difficult to cast by this process. Otherwise, there were very few aluminium engineering alloys which could not conveniently be cast. Notwithstanding what Dr. Frary had said about the roller-strip casting machine, he personally agreed with Dr. Scheuer that it had a definite future, once the engineering problems connected with it had been overcome.

Dr. V. Kondic suggested that the subject of continuous casting would be worthy of consideration as a subject for a symposium similar to that held on the conventional method of ingot casting. He had a feeling that Dr. Scheuer had painted in too black a picture the conventional methods of ingot casting. In comparing these with continuous-casting methods he thought that in the majority of cases the main factors would be favourable to one method, there were many cases in which the two methods were complementary.

Mr. J. Thexton said he was interested in the continuous casting of both ferrous and non-ferrous alloys with melting points above 1,300° C. and with casting temperatures of 1,450° C. or over and supplemented the paper with a few observations on the solidification of these high melting-point alloys in a continuous-casting machine. He expressed his views in relation to the three conditions of Dr. Scheuer's idea of casting process; namely, rapid heat extraction, directional solidification and the production of plane solidification front. In conclusion he thought the field for continuous casting of high melting-point alloys lay in providing billets of a comparatively small diameter, 6 in. to 9 in., but with a perfect surface finish, so that the initial breaking down stage in processing could be eliminated and the billets could go to a final rolling stage without prior treatment. In the steel industry, he thought the machine would be used primarily for the casting of high-alloy steels, such as the various types of stainless steels.

Monsieur Vinavier said that as far as his knowledge went attempts had been made to cast zinc by continuous casting but without very great success. It had not been possible to prevent the development of very coarse structure and serious difficulties had been met with in subsequent rolling of zinc slabs obtained by this method. Professor A. von Zeerleder said inverse segregation caused a lot of trouble in the production of aluminium alloys. When casting big ingots by semi-continuous or continuous processes indirect inverse segregation was sometimes found, especially with aluminium magnesium alloys, and some slides were shown to emphasise his point. Dr. P. Brenner referred to some work* by Dr. Kostron and himself on the macro- and micro-segregations of continuously cast as against chill cast ingots of two aluminium alloys. The macro-segregations had been found to be much lower in the continuously-cast ingots, whilst the differences in concentration within the cells were nearly the same in both continuously and in chill-cast ingots in the as-cast condition. But if the ingots were soaked at homogenizing temperatures, the micro-segregations were removed much faster in the continuously-cast ingots than in the chill-cast ingots as a consequence of the smaller size of the cells and the finer distribution of the eutectic in the inter-dendritic network.

Dr. Scheure replied briefly to the discussion.

GRAIN REFINEMENT OF ALUMINIUM AND ITS ALLOYS BY SMALL ADDITIONS OF OTHER ELEMENTS

By Myriam D. Eborall, B.A.

The effect of eight elements on the grain-size of sand-cast pure aluminium, and also that of titanium and boron on the grain-size of some aluminium alloys, has been studied. Several methods of adding titanium to the melts were used, and the efficiency of transfer of titanium was determined in each case. It was found that titanium, zirconium, and vanadium were the most effective grain refiners of pure aluminium, but that boron refined the grain of the copper-bearing alloys, its efficiency increasing with the copper content.

The grain-refining action of the added elements is not satisfactorily explained, but it is shown that (1) the presence of primary particles of intermetallic compounds is not necessary to initiate refinement, (2) a peritectic reaction does not necessarily produce fine grains, and (3) all the facts cannot be explained on the theory that grain-size is controlled by concentration gradients in the semi-solid casting.

The grain-size of aluminium containing small amounts of the grain-refining elements was markedly affected by the pouring temperature; this was not accounted for by the corresponding variations in rate of freezing in the mould.

The efficiency of transfer of titanium to the melts varied with the method of addition, and the efficiency of potassium titanofluoride was considerably reduced by the presence of magnesium in the melt. There was only a small variation in optimum titanium content with the method of addition.

THE MECHANISM OF GRAIN REFINEMENT OF SAND CASTINGS IN ALUMINIUM ALLOYS

By A. Cibula, M.A., A.I.M.

The work described in this paper was carried out to determine the mechanism of, and secure greater control of, the grain refinement of aluminium casting alloys of the solid-solution type and, in particular, to

* *Metallurgia*, February 1950

find ways of preventing grain coarsening and increasing the efficiency of refinement.

Measurements of the undercooling before solidification in castings of various aluminium alloys were correlated with the grain-sizes. Large additions of certain metals (e.g., copper and nickel) to pure aluminium partly refined the columnar structure to a coarse equi-axial one; this is ascribed to concentration gradients in the liquid round solidifying dendrites, which retarded crystal growth and the release of heat of fusion and thus allowed the interior of the casting to undercool and new crystallites to form there.

When very small additions of the powerful grain-refining elements (e.g., titanium, boron, niobium and zirconium) were made to pure aluminium, no undercooling was detected, indicating the presence of nuclei which facilitated the formation of crystallites of solid solution; but very fine equi-axial grain structures were obtained only when elements were present which produced concentration gradients during solidification and thus restricted growth of the first-formed crystals and allowed other nuclei to become centres of crystallization. Grain coarsening, due to the removal of nuclei from the melt by superheating, sedimentation, or the passage of gases, was also studied.

The experiments showed that, except in melts containing boron, the nuclei were not crystals of the intermetallic compounds of the refining metals with aluminium; theoretical considerations suggested that they were particles of the simple interstitial carbides of these transition metals These conclusions were confirmed by further experiments with aluminium-titanium alloys, in which titanium carbide particles were detected by X-ray examination after being concentrated by centrifuging the molten metal.

THE EFFECT OF GRAIN-SIZE ON THE TENSILE PROPERTIES OF HIGH-STRENGTH CAST ALUMINIUM ALLOYS

By A. Cibula, M.A., A.I.M. and R. W. Ruddle, M.A., A.I.M.

THE casting characteristics of light alloys are substantially improved by grain refinement and, in particular, that fine-grained materials are less prone to hot-tearing than coarse-grained materials of the same composition. It is also recognised that the grain-size of cast alloys may have important effects upon their tensile properties and this paper provides new information on this point. The work described was carried out to determine the cause of the deterioration in mechanical properties of castings in certain high-strength aluminium alloys, when high melting and pouring temperatures are used, and to explain the very adverse effects of a large grain-size in these alloys.

By varying the superheating temperature before casting, test-bars having different grain-sizes were produced from metal cast at the same temperature, thus making it possible to distinguish between the effects of grain-size and other factors depending upon the casting temperature. In this way, coarse- and fine-grained test-bars in aluminium—4·5% copper alloy (D.T.D. 304) were poured at each of several selected casting temperatures in the range 680°–900° C. Some results obtained with aluminium—10% magnesium alloy (D.T.D.300A) are also presented.

The tensile properties of these alloys were found to increase markedly with decrease in grain-size, owing primarily to changes in the form of the intergranular shrinkage cavities; the effect is greatest in the heat-treated alloys which contain only small amounts of brittle intergranular constituents. The adverse effects of high melting temperatures were due to the resultant increase in grain-size; methods of minimising this grain coarsening are suggested.

Discussion

Mr. A. Cibula presented the above three papers, after which Mr. R. W. Ruddle reported further work carried out since the papers were submitted for publication. Work had been carried out by Mr. A. L. Mincher to check the suggestion made by Mr. Cibula and himself that the relationship between tensile strength and grain size is affected by the rate at which the test bars are poured. The results of this work showed that the increase in grain size with casting temperature was substantially independent of the pouring rate. However. it was found that the soundness of the bars was quite markedly affected by pouring rate.

Dr. V. Kondic said that numerous points of theoretical as well as general metallurgical interest had been raised, but he confined himself to a consideration of the important finding disclosed that the degree of undercooling—other factors being the same—increased with the percentage of solute in the alloy. The few systems studied and discussed in the papers were not the only ones that behaved in that way, however, the interpretation of Mr. Cibula's finding was arguable on both experimental and theoretical grounds. A number of points he proposed dealing with in writing. Mr. C. S. Campbell thought the identification of the titanium carbides and tantalum particles was very interesting, but it would have been more interesting had it been extended to tungsten and molybdenum. Mr. A. W. Brace suggested the difficulty in assessing whether the actual values of percentages of grain-refining elements had any real significance because there was no information on what they meant in terms of carbides that brought about the refining. On this question of grain refining Mr. J. C. Chaston found it difficult to imagine that concentration gradients of the type postulated could exist in a bath of molten metal. There was so much evidence that diffusing in molten metal was extremely rapid. It was suggested by Mr. C. W. Cahn that the substructure referred to by Miss Eborall by up-etching sections of high purity aluminium quenched in the form of very irregular dentritic network, that it probably was some sort of dentritic phenomenon, which he briefly explained.

Dr. Marie Gaylor remarked that Miss Eborall's paper was very valuable in regard to the conclusions drawn, and her conclusions about the effects of peritectics on fine-grain structures were particularly interesting. One of the theories put forward for the modification of aluminium-silicon alloys was that the aluminium-silicon sodium system had a peritectic. The author had shown that a peritectic was not essential for grain refinement, and she had said that in the case of aluminium-titanium alloys that was definitely indicated by the fact that the method of addition of titanium affected the grain refinement.

Mr. Mountford referred to the influence of vibration in producing grain refinement. At the Physical Society recently, some interesting slides were shown; by vibrating aluminium-alloy melts at, he thought, 17 kilo-cycles, there was a distinct grain-refining effect. Referring to Mr. Chaston's remarks on concentration gradients, Dr. C. E. Ransley said such measurements had been made on the diffusion of metallic solids in aluminium. They had

the normal rate of division, so that it was quite clear that concentration gradients could be set up at normal casting speeds. He also asked whether the authors had any theory to advance as to where their carbide particles came from. Referring to some work on the effect of ultrasonics at his laboratories MR. A. N. TURNER said it was quite true that a very considerable grain refinement was obtained, as mentioned by Mr. Mountford, but it was only obtained when there was cavitation at the end of the probe.

Two practical points were raised by DR. SCHEUER. In the future only a few hundredths of titanium, easy to incorporate and to segregate, would be needed. In order to do that and obtain some practical results, it would be necessary to find out whether an alloy into which titanium carbide had been incorporated once would retain it in an active form after it was remelted an indefinite number of times. Had the authors any observations on this point? On a second point, he was interested in the graph showing the influence of the grain size on the mechanical properties of aluminium-copper alloy, and particularly in the data about the influence of the pouring speed. It might be a good thing to expand the study of this influence over a range of alloys.

MR. CIBULA and MISS EBORALL replied to the discussion.

SYMPOSIUM ON METALLURGICAL ASPECTS OF THE HOT-WORKING OF NON-FERROUS METALS AND ALLOYS

A whole day was given to the discussion of eight papers constituting this Symposium, which included hot-rolling, extrusion; hot-forging and hot-stamping of aluminium and its alloys, the hot-working of magnesium and its alloys, copper and copper alloys, tin bronzes, lead and lead-rich alloys, and the rolling of zinc and zinc-rich alloys, and it was not by any means too long. The presentation of these papers certainly provided opportunities for free and full interchange of knowledge amongst workers pursuing similar lines of study which were fully appreciated and taken advantage of in providing one of the best discussions experienced in recent years. Although it would be impossible here to do justice to this Symposium and the discussions, a brief summary will be of interest.

THE HOT-ROLLING OF ALUMINIUM AND ITS ALLOYS

By F. KASZ, B.Sc. and P. C. VARLEY, M.B.E., M.A.

THE term hot-rolling used in this paper includes all rolling operations carried out on the hot mill, irrespective of whether recrystallisation is taking place or not. The first part gives a description of current practice in the hot-rolling of aluminium, together with a discussion of the various considerations leading to the preheating of the rolling blocks is considered. The second part contains an amount of the physical and metallurgical aspects of hot-rolling, including a detailed discussion of the mode of deformation and its bearing upon some of the problems mentioned in the first part. The effect of hot-rolling upon the metallurgical constitution of the metal is also considered and some indication is given of the influence of hot-rolling variables upon the behaviour of the product after final cold-rolling to gauge.

THE EXTRUSION OF ALUMINIUM ALLOYS

By CHRISTOPHER SMITH, F.I.M.

IN this paper the extrusion process is described, with special reference to its use for aluminium alloys. Some information is given on the practice employed in die manufacture, and the nature of the flow that normally occurs in the extrusion of non-ferrous alloys is briefly considered. The particular conditions which may arise in the extrusion of aluminium alloys are described, and the dependence on these conditions of the type of structure and properties obtained is discussed. Problems associated with the production of heat-treated alloys in the form of extrusions are also dealt with.

THE HOT-FORGING AND HOT-STAMPING OF ALUMINIUM AND ITS ALLOYS

By F. E. STOKELD, F.I.M.

THE essentials of forging are so fully covered, whatever the metal to be forged may be, that the author considered it unnecessary in the present paper to discuss such normal requirements. There are, however, certain differences which ought to be taken into account when the forging of aluminium alloys is being considered and some of these are briefly mentioned. All authorities agree that aluminium alloys require greater force than does ordinary steel, because the material flows less readily at the forging temperature. The general aspects of forging aluminium and aluminium-rich alloys is reviewed. The difficulties associated with the accurate estimation of the values of strength and ductility ruling at particular locations in forgings of the aluminium alloys are already well known, but the aircraft industry, especially, requires assurances of minimum values at various locations in important forgings. This problem is discussed, together with the influence of various factors which have a bearing upon it, such as the alloy used, the forging stock, its size, method of manufacture, the methods and temperatures employed during the forging and subsequent heat-treatment operations, and the final shape and flow lines produced in the various parts of the forging itself, etc.

THE HOT-WORKING OF MAGNESIUM AND ITS ALLOYS

By R. G. WILKINSON, B.Sc. and F. A. FOX, D.Sc., F.I.M.

SERIOUS progress in the economic hot-working conditions for magnesium base alloys has only been established during the last 15 years, the most production period in this respect being during the early stages of the recent war. In the present paper the authors review and discuss the metallurgical factors which have emerged and show how magnesium alloys have progressed from a stage when they were regarded as somewhat freakish materials, which could be fabricated into wrought products only by careful "nursing," to one in which they are capable of withstanding drastic working conditions such as have been applied to mild steel for many years, and more recently to aluminium-base alloys. Great advances in quality and economy of production have taken place in recent years. Considerable emphasis is given to the importance of the direct-chill casting process; stock so produced in the new zirconium-containing high-strength alloys can be hot-worked over a wide temperature range, use of initial temperatures as high as 500°–520° C. permitting heavy reductions to be effected without failure. Short accounts are given of U.K. and U.S. development projects which have shown that modern magnesium-base alloys can be hot-worked under drastic conditions similar to those which are applied to mild steel, and comments are made on some

possible future lines of development. The compositions and properties of the principal alloys are given, and the effects of varying working conditions are indicated.

Discussion

In introducing the above four papers Dr. C. J. Smithells gave a brief summary of their essential features and drew attention to some of the problems likely to be less understood or whether views other than those given by the authors might be put forward. Concluding, he said that whilst the four papers cover a variety of hot-working processes to which light alloys are subjected, there are certain principles common to all of them. First and foremost, the importance of starting with a cast material which is fine grained, free from porosity, segregation and internal stresses, and with a good surface. Secondly, a careful control of the temperature at which the hot-working operations are performed. Thirdly, the advantage in nearly all cases of giving the most drastic reductions of which the plant is capable at the highest speeds.

Mr. R. Chadwick said one of the authors had defined hot-working as working at temperatures appreciably above the recrystallisation temperature. In the papers presented, what is termed hot-working may or may not involve recrystallisation. Moreover, the recrystallisation in many of the alloys concerned is a very complex phenomenon, so that the actual changes occurring are seldom fully understood. Only perhaps with super-pure aluminium are conditions at all similar to those occurring in the more familiar copper alloys. He raised several other points and supported his discussion with a number of slides. Mr. Pearson referred to some remarks by Kasz and Varley on the effect of block structure in the rolling of aluminium alloys. It is surprising that the block structure does in fact survive through rolling one and even more than one stage of recrystallisation. He illustrated this with a slide.

Mr. W. C. F. Hessenberg confined his remarks to the paper by Kasz and Varley which shows a nice appreciation of the way in which metallurgy and mechanics are mixed up in these problems. He thought there was slight confusion between the residual stresses, left in the slab after rolling and the actual stresses causing crocodiling, referred to in the work of Baker, Ricksecker and Baldwin. What Baker and his colleagues did was to measure the residual stresses and then deduce from these what were the actual stresses in the metal as it left the rolls which caused the crocodiling. A question relating to stagger was replied to by Mr. Varley. Dr. Smithells sought further information from Mr. Hessenberg regarding the radius of curvature of the rolls which was clarified. In view of Mr. Hessenberg's remarks Professor O'Neill read a written contribution from Mr. Polakowski.

Mr. J. C. Swan said that for hot-rolling they do not use slabs exceeding 5½ in. thick and no crocodiling trouble is experienced on pure aluminium. All their trouble in hot-rolling is confined to edge cracking. With chill-cast slabs that is due to casting at too low a temperature or at too low a speed. With continuous-cast slabs, tearing is usually due to stress cracks along the edge.

Mr. Josiah Jones took the liberty of exaggerating statements made in the paper by Mr. Stokeld, who said we can make good forgings; Dr. Sachs, on the other hand, said in 1939, if we make a forging at all, we are lucky. Particularly is he emphatic in saying that if we want to make a good forging, we must use straight duralumin and not attempt anything better. He is very detailed about the difficulties in making high-strength forgings. The high-strength alloys, he suggests—if we succeed in making forgings without obvious cracks—will have considerable directionality—i.e., a high property in the longitudinal and a lower property in the transverse. He then says that we will get a considerable spread of results. Lastly, he says that we should simply save ourselves the disappointment of trying to make complicated forgings.

Unhappily, in the aircraft industry these are all the properties that we want. More than ever modern aircraft design is demanding the complicated forging in order to cut down joints and so eternally to try and save weight. A minimum spread of results is an essential demand of the aircraft engineer, because he must design on the bottom value and not on the top, much less the average. Lastly, with regard to the directional properties, often in an aircraft structure there is stress in all three directions, and again the designer has to design on the minimum conditions.

Professor H. O'Neill referring to the paper by Kasz and Varley mentioned a statement that the top surface of the rolled metal is more heavily worked than the bottom, and that the upper roll momentarily transmits more power. Is there a case for independent motors to drive the two rolls? Commenting on the paper by Wilkinson and Fox he referred to an illustration he could not follow, and it was found that he had somehow managed to get an uncorrected proof copy of the paper.

Mr. F. E. Stokeld was sorry to hear Mr. Jones quoting Dr. Sachs' paper; nowadays the forging industry is concentrating upon producing the properties that are required in forgings in specific locations in those forgings, and the results are judged by taking test pieces from those locations. The industry is engaged in producing forgings with those properties present, and we are of course endeavouring to use the high-strength alloys—and succeeding very largely.

Mr. C. E. Davies expressed his interest in the mechanical aspects of the hot-working of metals and particularly in the paper by Kasz and Varley. From a mechanical point of view it seems that in rolling thick slabs heavier reductions are required. Mr. Hessenberg suggests a larger roll diameter is to be preferred, but he disagreed. The size of roll used in breaking down aluminium ingots is usually 34 in. to 40 in., or something like that, and when there is an increase in the width of the slab and greater power, a bigger roll still will be wanted, and it may become impossibly large from the practical point of view. This seems to lead to the point of view that we shall have to consider what is already done in America and have the four-high mill for the earlier breaking down of heavy ingots.

Many other members took part in the discussion, including Mr. Tate, Mr. Simmons, Dr. Fox, Professor Murphy, Mr. Freeman Horn, Dr. Doyle, Mr. Walters, Mr. Bond-Williams, Mr. C. Smith, Mr. Berry, Dr. Jenkin, and finally the Chairman who said that the discussion had proved both interesting and fruitful.

Four further papers included in the Symposium were introduced by Mr. G. L. Bailey, following lunch, and those taking part in the discussion included Mr. H. W. Hingett, Mr. Harry Davies, Mr. Lloyd, Mr. R. Chadwick, Monsieur Vinavier, Mr. Hughes, Mr. Stokeld, Mr. B. Walters, Mr. R. E. Berry, Mr. E. Davis, Professor Murphy, Mr. F. C. Evans, Mr. W. T. Butcher, Dr. M. Cook, Mr. A. Latin, Mr. G. L. Bailey, and a hearty vote of thanks concluded the meeting.

Heat Treatment of Steel Forgings for Gas Turbines

By H. W. Kirkby, F.I.M., A.Met.
The Brown-Firth Research Laboratories

The development of the long-life gas turbine for use in power stations and for marine propulsion has resulted in a demand for large forgings in materials capable of operating at high temperatures for long periods. In order to develop the required properties it is necessary to carry out heat-treatment operations at temperatures of the order of 1,200° C., followed in some cases by quenching. This combination of large mass and high temperature is unique in the heat treatment field and many metallurgical and handling problems arise.

PRIOR to the successful development of the gas turbine in the form of the aircraft jet engine, the barrier to a more efficient and thereby more general application of the gas turbine was the limitation of the high-temperature strength of materials available at that time. Perhaps more than any other factor, the aircraft jet engine has given a stimulus to metallurgical researches in regard to providing materials which could withstand higher gas temperatures under highly stressed conditions.

The first important stride in material development was made with the introduction of R. ex 78 austenitic creep-resisting steel in 1936. Since then, a relatively large number of alloys have been produced, capable of withstanding conditions of stress and temperature hitherto considered impossible.

Some idea of the progress made and of the range of materials available to-day can be judged from the accompanying graph (Fig. 1), which compares a number of materials in terms of strength (on the basis of fracture in 1,000 hours) at various temperatures. To give perspective, carbon and carbon-molybdenum steels have been included in the graph, the properties of these materials being known.

Following on the war there has been considerable activity in the field of design and application of relatively large gas turbines for long-life land and marine purposes. This in turn has necessitated further investigations into the capabilities of various materials to withstand very long periods at elevated temperature with limited deformation, as distinct from the short life required in the jet engine.

It has also been necessary to investigate various processes in connection with the practical production of relatively large forgings in these highly alloyed materials, which by their very nature are more difficult to forge and heat treat than the ordinary carbon or low alloy steels. Progress in this direction can be judged by the fact that recently a 33-in. diameter (body) solid rotor shaft with a total length of 16 ft. was forged in one of the complex austenitic steels, and finally heat treated by water quenching from 1,250° C. (See Fig. 2). This forging is probably the largest of its kind ever made either in this country or abroad.

Materials

Developments in high-temperature materials have been on a broad basis, comprising iron-base (steels), nickel-base and cobalt-base alloys. Both iron and nickel-base alloys have been, and are being, used extensively in aircraft jet engines in this country, but little or no service experience is available of the cobalt-base alloys.

In the case of the long-life gas turbine, the larger components are almost entirely confined to iron-base alloys in the form of forgings. As a result of this, subsequent discussion will be confined to the latter type of alloy.

The steels being used or under consideration for the long-life gas turbine can be placed into two major categories :—

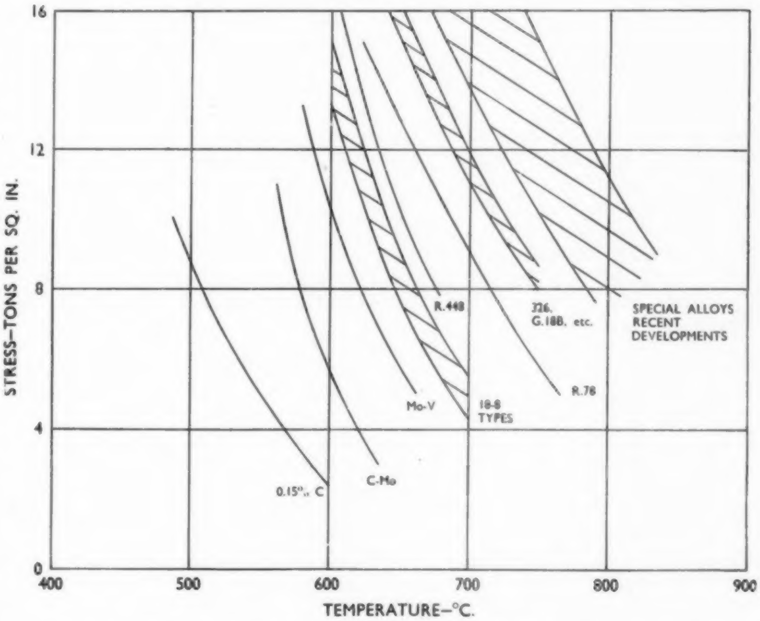


Fig. 1.—Graph showing the stress to fracture in 1,000 hours plotted against temperature for a number of materials.

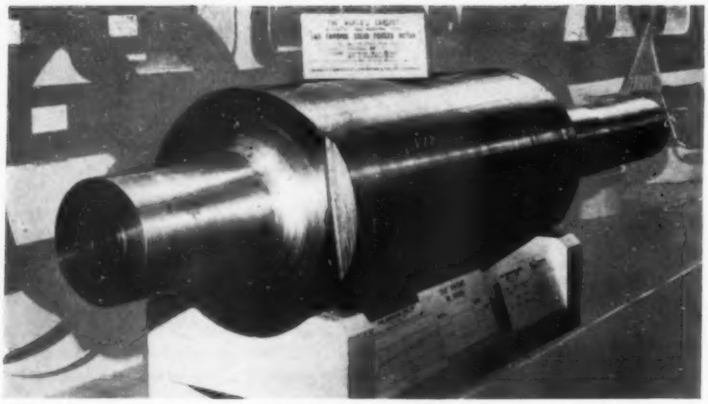


Fig. 2.—A large gas-turbine rotor forged in a complex austenitic steel and water quenched from 1,250° C.

A *Ferritic Steels.*—These are mainly the molybdenum-vanadium types with or without chromium and tungsten. In most cases the plain molybdenum-bearing types lack the necessary creep resistance.

B *Austenitic Steels.*—These are usually of the nickel-chromium type, with additions, for example, of niobium, titanium, molybdenum, cobalt, etc.

In general, the production and heat treatment of the ferritic steels follow normal low alloy practice. Here, as a result of steam power plant practice, a wide range of experience is available for a variety of products, including very large forgings. If anything, the heat treatment of the vanadium-bearing steels is probably more critical for optimum creep resistance, but there are no special problems compared with some of the special austenitic materials.

The ferritic steels are generally normalised or oil quenched from temperatures of the order of 950°–980° C. for plain molybdenum-vanadium types, and a little higher when chromium is introduced, say 1,000°–1,050° C. In most cases, tempering is carried out, usually in the range 650°–700° C. It is of interest that recent work has shown that tempering close to 700° C. actually improves the creep resistance of normalised molybdenum-vanadium steel[1] which is contrary to the experience with most low alloy steels.

In the last few years, however, there have been demands from the engineer for ferritic steels which will have creep properties superior to the molybdenum-vanadium types with, of course, the necessary scaling resistance.

In this connection there have been some promising developments in the field of ferritic steels and one of these materials, R. ex 448, has creep properties similar to the stabilised 18/8 type of austenitic steel (see Fig. 1). This type of steel is, of necessity, much more highly alloyed than the normal ferritic material. Furthermore, in order to achieve the desired creep resistance, these special ferritic materials demand heat treatments above the general range of heat treatments accorded low alloy steels. Thus the hardening or solution temperatures used are found to be intermediate between the normal ferritic steels and the complex austenitic steels. Like the complex austenitic steels, the special ferritic steels demand a similar precision in regard to the control of heat-treatment temperatures and general handling.

In the case of the austenitic steels, these can be sub-divided as follows :—

I 18/8, 18/10, 18/12 chromium-nickel types stabilised with titanium or niobium. Molybdenum may be used with or without a stabiliser.

II Complex austenitic steels—iron based, using nickel and chromium in austenitic proportions with additions of molybdenum, vanadium, tungsten, cobalt, copper, titanium, niobium. Usually several of these elements are present together.

Solution temperatures employed for the austenitic steels differ for the different groups and are usually about 1,050°–1,150° C. for Group I and 1,200°–1,300° C. for Group II. Group I steels do not present any very serious problems in regard to heat treatment. Group II materials, however, require careful handling and most of the following discussion concerns this latter type.

Metallurgical Factors

Many of the present-day special austenitic steels are considered to owe their high creep resistance to a favourable precipitation of alloy carbides and, probably, intermetallic compounds. This is achieved, in common with many alloy systems, by solution at some relatively high temperature followed by reheating at some intermediate temperature. The mode of precipitation encountered in one type of alloy can be seen by comparing Fig. 3 (as heat treated) with Fig. 4 (after 2,000 hours at 700° C.). This type of precipitation only became evident after long periods of heating at elevated temperatures.

While there are some variations in the temperatures employed for the different austenitic steels, the majority of the complex types require solution-treatment temperatures in the range 1,200°–1,300° C. Subsequent cooling may be in air, oil or water, depending upon the type of steel, size, properties required, etc. In general, creep resistance improves with increase in solution temperature and, therefore, careful consideration must be given to the relationship between the solution temperature and the " burning temperature " of a particular composition. This term denotes the onset of incipient fusion, which commences at the grain boundaries and/or in regions of massive undissolved carbide. In most cases the reaction is essentially a eutectic one. Where severe, the material fractures under its own weight at solution temperature, but in less severe circumstances the only evidence of the trouble is some degree of deficiency in room temperature ductility. Creep resistance is not necessarily affected provided the excessive temperature has not resulted in actual separation at the grain boundaries. As a result of this, the temptation to employ solution temperatures too close to the burning temperature must be resisted in practice, since temperature control in the range in question is no easy problem. In addition, experience indicates that burning temperatures are likely to fluctuate, to some extent, from cast to cast.

1 Glen, J. "The Creep Properties of Molybdenum, Chromium-Molybdenum and Molybdenum-Vanadium Steels." *Journal of the Iron and Steel Institute.* Jan., 1948. pp. 37-80.

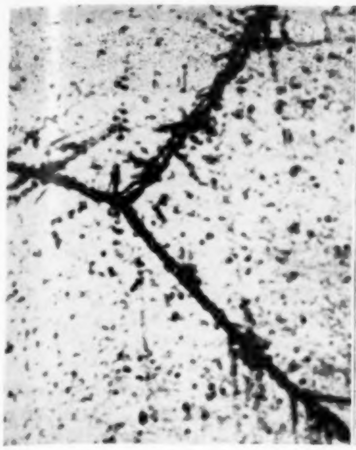


Fig. 3.—Photomicrograph of a complex austenitic steel in the heat-treated condition. × 2,000

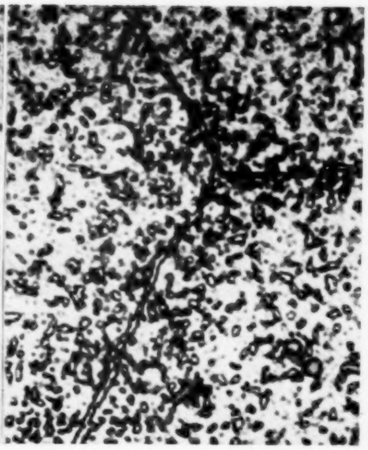


Fig. 4.—Photomicrograph of the same steel after 2,000 hours at 700° C. Air cooled. × 2,000

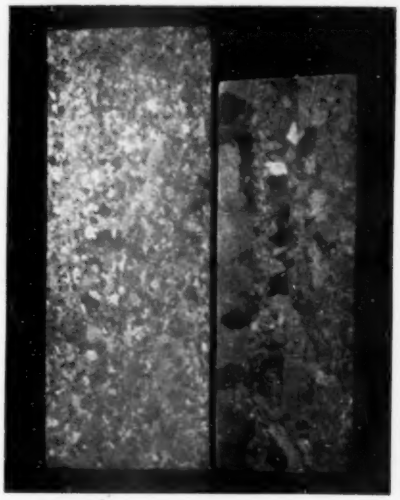


Fig. 5.—Examples of "explosive" grain growth in a complex austenitic steel. (Actual size)

A variable response as regards "burning" is probably even more marked when size of product is considered in some compositions. Thus a serious drop in burning temperature and other deficiencies may occur as a result of macro and micro segregation features when forgings are made in certain compositions. Experience with small diameter bar stock gives no indication of this trouble, but it can generally be overcome by modifications in analysis.

At the author's own company, it is the usual practice to sample material corresponding to the top-end centre position of forgings which, either because of size or composition, represent a production on which experience is not available, and then to carry out a series of solution heat treatments in the laboratory. By this means a safe solution temperature can be worked out and this can be related to bar stock experience to ascertain whether any serious discrepancies in relative solution temperature exist. In this respect some advantage has been found, in certain cases, in carrying out "step-solution" treatments; for example, where 1,250° C. is the required solution temperature, the approach is made in something like the following manner, in the case of a fairly large forging: 4 hours, 1,150° C.; 2 hours, 1,175° C.; 2 hours, 1,200° C.; 2 hours, 1,225° C.; and 2 hours, 1,250° C.

A further feature which may restrict the use of the ideal solution temperature is the abnormal propensity to grain growth of some materials when heated to high temperatures. This type of grain growth is sometimes called "explosive" grain growth because of the rapid nature of the phenomenon. It has been found that materials differ widely in this respect and the general trend appears to be in the direction of increased susceptibility the better the creep resistance of the alloy. Fig. 5 illustrates examples of the "explosive" grain growth phenomenon found in bar stock of a complex austenitic steel after 1 hour at 1,250° C.

This variability of solution-treatment grain growth has been connected directly with the initial thermal history of the particular material. Even so, control in practice is very difficult with certain sizes of product and more is required to be known before this phenomenon can be rigidly controlled.

As this type of grain growth is time-sensitive, advantage can sometimes be taken by the use of short-time solution treatments compensated by a slightly higher temperature. Obviously, this latter procedure has strict limitations in regard to size of forging and other means may have to be adopted.

The main objection to abnormal grain growth lies in the deleterious effect on the resistance to fatigue both at room temperature and at elevated temperatures. Creep resistance is not adversely affected and, if anything, may be improved. Ductility under creep conditions generally suffers, however, under these conditions.

Heat Treatment

It will be appreciated that bulk heat treatment as understood in carbon and low alloy steel practice is almost impossible to carry out satisfactorily when dealing with the complex austenitic steels, because of the difficulties connected with temperature control and uniformity in the range 1,200°–1,300° C. As mentioned previously, creep resistance is directly related to the solution temperature and, as many of the products are used for components which carry high centrifugal stresses in service, the importance of correct heat treatment cannot be over-emphasised.

Heat treatment of bar and small forgings generally follows high-speed steel practice, except that protective atmospheric requirements are not so critical, since in many cases the products are not in a finished machined condition. Where size and finish are important, high temperature salt baths are being used. This relates, of course, to the smaller products such as bar and drop stampings—e.g., turbine blades. Fig. 6 illustrates a salt bath (2 ft. diameter × 3 ft. deep) installed recently for this purpose. In the case of bars, length is kept to a minimum, say 3 ft., or, where possible, smaller. This greatly assists the attainment of a uniform temperature and enables individual treatment to be given to each piece.

In the case of a forging, such as a disc, up to say 20 or so inches diameter, a more uniform product can be obtained by heat treating individually or in small

Fig. 6.—A salt bath used for the high-temperature treatment of such products as turbine blade drop stampings.

batches. Individual heat treatment is preferable in all cases wherever it is practicable, that is, if a satisfactory pre-heating cycle can be adopted and the particular material is responsive to short times of heating. It should also be remembered that, in general, it is the rim of the disc where optimum creep resistance is required. As this is the position which first attains full temperature, control can be based on this particular portion of the material.

Larger forgings of the rotor variety, as for example, the 33-in. diameter rotor shaft mentioned earlier, require extra care, as the handling problem is formidable and demands considerable experience. Up to now it has been the practice to employ heat-treatment furnaces which would house rotor shafts many times the size of the largest austenitic steel forging made to date. The reason for this is that close uniformity for heat-treatment purposes at, say, 1,250° C. is difficult to attain in most present-day designs of furnace, and in a furnace just large enough for the forging, thermal gradients over the length and width of the piece are considerably greater than those on the same forging in a much larger furnace. In addition the use of the larger furnace lends itself to adopting a muffle principle which aids uniformity, namely, by boxing in the forging with a structure of loose firebricks, or some similar device, which can easily be removed when required. For temperature measurement, platinum/platinum-rhodium thermocouples are distributed liberally round the forging and these are supplemented with optical pyrometers, for the use of which sighting holes are left in the firebrick walls. The author's company have used this procedure with satisfactory results for all types of forgings up to 40 in. diameter.

After the larger type of forging has been heat treated in the furnace, there still remains the problem of handling it. The problems are intensified if the forging is required to be water quenched, since it is necessary to pick up the forging reasonably quickly to avoid loss of temperature. If the forging is of a long slender type, such as a rotor with long shafts, then quenching must be done vertically and a water tank of the necessary depth, with circulating equipment, must be available. In such a case the manner of slinging is of the utmost importance, since bending of the shafts can readily occur if sufficient care is not taken. In addition precautions must be taken to avoid the chains and supports being at too high a temperature, where the forging is in the heavy category. Such problems have been solved by utilising the experience obtained in the past in the handling of large forgings which have been heated to forging temperature and require transferring to the press, etc. In some cases new methods of approach have had to be made to overcome this handling problem.

After solution treatment some steels may not require any further treatment. In other cases an ageing treatment may be required, in which case this is usually carried out in the range 650°–800° C. for periods extending up to 48 hours. The problems in this type of treatment are not so formidable as those which arise when dealing with solution treatment temperatures. Nevertheless, uniformity and close temperature control are still important in order to obtain the desired creep resistance, and the remarks made in connection with solution treatments also apply, in most instances, to ageing treatments.

The final check on the adequacy of the heat treatment accorded the forging consists of carrying out creep tests and, in some cases, room temperature mechanical tests, from selected positions and making comparison with known data obtained on bar and other types of forgings of the same material.

To sum up, the heat treatment of gas-turbine steels offers no serious difficulties in the case of the normal ferritic steels and the lower-grade austenitic steels. Problems arise, however, when dealing with large forgings in the more complex austenitic steels on account of the high solution temperatures employed. To date, the approach to the heat treatment of alloys in this latter category has, on the whole, been conventional, wide use being made of existing plant, but with additional precautions.

Engineering Equipment Users Association

FIVE companies in the process industry field, namely :—Anglo-Iranian Oil Co., Ltd., Courtaulds, Ltd., Imperial Chemical Industries, Ltd., Lever Bros. & Unilever, Ltd., and Shell Petroleum Co., Ltd., have formed an Association called the Engineering Equipment Users Association, which will provide its members with a means for exchanging information on standardisation of engineering materials and equipment which they use in common.

The new Association will work through the British Standards Institution on matters of general standardisation and will assist that Institution by presenting, as far as possible, the co-ordinated views of its members' representatives who serve on B.S.I. Technical Committees, etc. Brigadier L. F. S. Dawes has been appointed Secretary and the offices are at 20, Grosvenor Gardens, S.W.1.

Focus on Quenching

By R. C. Stockton, A.I.M.*

The importance of the cooling rate in heat treatment operations is frequently overlooked; just as in heating, however, all the factors of time, temperature, mass and surface are involved in cooling, and their proper adjustment is as necessary as in heating, in order that the finished product shall be uniformly good.

PROMINENT as a contribution to the progress of modern engineering are the advantages which have accrued from metallurgical control of heat treatment. Furnace design and related heating methods reflect this influence, whilst the equally significant functions of cooling in the development of the desired physical properties in the metal have not been overlooked. Almost departed are the days when the water "bosh" was an improvised receptacle containing a liquid resembling water, but probably covered with a film of oil and a companion quench tank holding a foul looking liquid with a pervading odour and the courtesy title of oil. Quenching, however, is assuming its rightful dignity, is a vital factor in heat treatment and as such, should receive as much consideration as the heating operation. It is, in fact, almost as diverse a subject, as might be expected in view of the ever widening range of metals and alloys which need heat treatment.

A broad conception of quenching is that it is practised on metals to secure and retain at room temperature, permanently or temporarily, a physical condition which normally exists only at a different one or, in some cases, to exercise selective transition, as in the hardening of carbon steels. Quenching does not necessarily imply hardening as this is specifically avoided, at least temporarily, in the heat treatment of some light alloys where the metal hardens up only after a time lag, the interim period permitting cold working of the alloy. Again, quenching may follow annealing without measurable effect on hardness but preventing undesirable structural development. An ancillary use of quenching is also unrelated to either hardness or structure, as with salt bath annealed metal which may be quenched into hot or cold water merely to facilitate removal of the salt. Some licence is exercised in using, for clarity, the term "quenchant" to denote the quenching medium.

It will be appreciated that various media are necessary to give varied rates of cooling related to the peculiarities of the metal and that a modern heat-treatment shop will need to have several available for regular use as well as facilities for those required infrequently. By and large, the most used are water, saline solutions and oil, with hot liquids such as molten lead and salt employed more in specialised operations to be described later. Selection of a quenchant is assisted, in a broad sense, by the heat-treatment specification, but "oil" is a loose term and even water can be modified by small additions of various salts to improve its performance. Hence, if one is not to make the exploratory tests to determine the suitability or otherwise of a liquid for quenching particular steels or work, some guidance is necessary. For this reason the following tables are included.[1]

TABLE I

Quench, Medium in % by Weight	Sp. Gr. at 15·5° C.	Still or Ft./sec.	Quench Temperature	Relative Quenching Rate at 20° C.*
2·5 Sodium Chloride ..	1·018	Still	20° C.	0·78
5 ,, ...	1·036	,,	,,	1·12
5 ,, ...	—	3	,,	1·14
10 ,, ...	1·073	3	,,	1·23
15 ,, ...	1·111	3	,,	1·27
20 ,, ...	1·151	Still	,,	1·06
20 ,, ...	—	3	,,	1·11
26·4 ,, ...	(Saturated)	Still	,,	0·78
26·4 ,, ...	1·204	3	,,	0·81
2·5 Sodium hyd'ide, 98%	1·029	Still	,,	1·19
5 ,, ...	1·058	,,	,,	1·17
5 ,, ...	—	3	,,	1·20
10 ,, ...	1·113	3	,,	1·20
15 ,, ...	1·169	Still	,,	1·14
15 ,, ...	—	3	,,	1·11
20 ,, ...	1·222	3	,,	1·07
50 ,, ...	1·529	3	,,	1·05
5 Calcium chloride ..	1·042	Still	,,	1·06
10 ,, ...	1·085	,,	,,	1·17
20 ,, ...	1·179	,,	,,	1·06
Water	—	,,	,,	1·00
,, ...	—	3	,,	1·01

* Cooling rate of 180° C. per second in still water at 20° C. — 1·00. Specimen used in all comparative quenching tests was a cylinder 0·50 in. dia. by 2 in. long in 0·96% carbon steel.

TABLE II

Quenching Media	Still or Ft./sec.	Relative Quenching Rate at 20° C.*
Prepared oil No. 1	Still	0·44
Prepared oil No. 2	,,	0·35
Mineral Oils		
Transformer oil	Still	0·17
Machine oil	,,	0·22
Paraffin oil	,,	0·29
Fuel oil	,,	0·36
Vegetable Oils		
Palm oil	Still	0·15
Rapeseed oil	,,	0·22
Castor oil	,,	0·29
Cottonseed oil	,,	0·36
Olive oil	,,	0·37
Animal Oils		
Lard oil	Still	0·19
Fish oil	,,	0·31
Sperm oil	,,	0·33
Neatsfoot oil	,,	0·33

* Cooling rate of 180° C./sec. in still water at 20° C. — 1·00.

Most of the tests on which these tables are based were made in a "still" quench with a small test piece so that, were the liquid in motion, any increase in the rate of quench must be inferred to be slight. In addition to the oils mentioned in the tables, there are proprietary brands of quenching oils available which have fixed physical properties but are blended to give the best

* Director, Tool and Die Heat Treatment Co., Ltd., Sheffield.
1 A.S.M. Handbook.

compromise between the desirable properties and those less so, of the individual constituents.

A study of the tables will show how variations in the concentration of aqueous solutions affect the cooling rate which can fall away in both directions from a given concentration and, in the case of sodium chloride, can actually drop well below that of water. A rise in temperature of the quenchant, excepting oil in certain cases, invariably reduces the cooling rate, but advantage is taken of this to secure intermediate rates of cooling between the extremes provided by cold salt solutions and oil. The efficiency of the quench is also modified by the surface condition of the cooled metal and by the ease with which the quenchant volatilises to create a gaseous envelope around the work. A scaled or otherwise dirty surface condition of the quenched metal can nullify all the care taken in the selection of the quenchant, as patchy hardness and even local soft spots frequently result.

Characteristics of Quenchants

If air be temporarily ignored, oil provides the mildest type of quenchant in common use. A range of cooling rates is covered by the oils now available for quenching, catering as they do for the many types of steel which harden adequately without resorting to a water quench. The open flash point of the oil should be as high as possible, whilst it is important to avoid a fatty acid content if it is proposed to use the oil for quenching work directly from a salt bath using highly alkaline salts, as saponification will produce soaps with the probability of obstruction where a circulating cooling system is in use. Other things being equal, the choice will lie with the oil having the highest open flash point, the lowest viscosity and freedom from fatty acids. If these virtues are allied with an inoffensive odour when hot, so much the better.

Water, of course, has a higher quenching rate than oil. It is a medium which can be considered universally constant as far as the significance of its soluble impurities is concerned. As would be expected, it is probably more widely used than any other quenchant because it is employed with a wide range of carbon and carburised steels, with specialised application to certain low alloy steels as, for instance, in induction surface hardening; it is also used in light alloy treatment. The evolution of dissolved gas and the generation of water vapour at the quenched face of the metal are possible sources of trouble, nor is water a particularly effective agent on scaled metal. The temperature, additionally, must not be allowed to rise if repetitive uniformity of hardness is to be secured. Some of the disadvantages of water have been overcome by using various aqueous saline solutions. Calcium chloride, sodium chloride and caustic soda are all used as additions, but there is still room for research in this matter, as the salts so far used have a number of disadvantages, with the one notable advantage of low cost. Sodium and calcium chlorides cause serious post-heat treatment rusting unless removed carefully by thorough washing, whilst there is an element of danger in the use of caustic solutions which also suffer from instability due to absorption of carbon dioxide, this converting the hydroxide into the carbonate. Caustic solutions, therefore, should be kept covered when not in use and be remade at frequent intervals. The advantages of such saline solutions are that they can offer a higher quenching rate than water; they can be used at reasonably high temperatures to give a comparable cooling rate to water; they "wet" the metal much more effectively; and, particularly in the case of caustic soda solution, they are very effective in detaching scale from the metal to give a more uniform quench. A further advantage is that they do not occlude gases nor do they so readily evolve water vapour. In general, steel quenched into such media has a cleaner appearance than when water quenched. The caustic soda solution is the simplest to use of these saline quenchants, as its properties do not vary much with concentration, whilst it has no tendency to cause rusting. In the U.S.A. hot solutions of caustic soda, held around 65° C., are used extensively in preference to oil for the heat treatment of many alloy steels.

In any consideration of quenching agents, molten media, such as salt and lead, must have a prominent place. The latter has been a favourite for very many years in the patenting of steel wire, this process having been for so long an unconscious example of iso-thermal treatment. Lead has also been used in the past, and is possibly used nowadays in odd cases, for quenching high-speed steel, although its main function in such an application is to prevent or reduce distortion rather than to act as a coolant. However, for this work it has been superseded largely by liquid salt which serves just as well but enjoys a lower specific gravity than the quenched metal. Molten salts, essentially nitrate or nitrate-nitrite mixtures, have proved invaluable in both iso-thermal treatment and martempering. It may not be appreciated that such salt has a cooling rate at 250° C., as determined by Lueg and Pomp,[2] equal to the optimum rate possible with oil used at 20° C. At 349° C., a cooling rate of 127° C. per second has been obtained on a 0·47 in. dia. steel ball. Such nitrate salts do not evolve gas, nor do they volatilise below about 550° C. whilst more stable salts, mainly chloride mixtures, are available for cyclic annealing at higher temperatures. A note of warning on two counts, must be sounded concerning the use of fused nitrate or nitrate-nitrite mixtures for quenching. Firstly, on no account must high-speed steel at the hardening temperature be quenched into such mixtures as both tool and bath may disappear violently and, secondly, a similar danger exists when quenching work from a cyanide bath, when martempering or practising iso-thermal treatment, unless the cyanide content of the bath does not exceed 5%. This is due to the violent way in which nitrates and cyanides can react.

Cooling Systems

An axiom of quenching is that after selection the quenchant should be used at its maximum efficiency. Any quoted cooling rate applies at a fixed temperature only; it is vital, therefore, to supply a uniform and adequate volume of quenchant to the hot surface of the metal at a constant temperature, within reasonable limits. This implies motion which may be achieved by agitation or, preferably, by circulation, in which case cooling should be incorporated. In a static quench, agitation can be simulated by moving the work upwards and downwards or in a circular path, whilst small components meet sufficient cool quenchant by being dropped into the quench bath, with the proviso that an ample depth is available. Such quenching equipment cannot, however, cater for a large throughput of work.

Some conception of the quantities of quenchant required for a known output of hardened work is, of

[2] Stahl & Eisen, Vol. 61, 1941.

course, necessary. Approximately 1–2 gallons of water or oil per lb. of steel quenched per hour should cover most needs, the higher figure applying when there is little or no circulation or cooling and the lower figure when the reverse obtains. The formula[3] given below permits calculation of the theoretical minimum volume of the quenchant which must come within effective proximity to the metal in a given length of time.

$$V = \frac{W^1 \times SH^1 \times (T^1 - T^{11})}{SH^{11} \times W^{11} \times TR} \text{ cu. ft. where,}$$

W^1 = weight of material quenched.
SH^1 = mean specific heat of material quenched.
T^1 = temperature of heated material.
T^{11} = temperature of material at time of removal from quench.
SH^{11} = specific heat of quenching medium.
W^{11} = weight per cu. ft. of quenching medium.
TR = permissible rise in temperature of quenching medium.

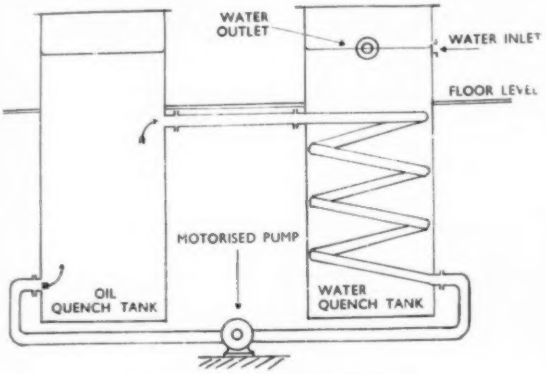


Fig. 1.—Oil-cooling system.

The simplest method of cooling an oil-quench tank is to surround it with a jacket through which water is circulated. The efficiency is, however, low and heavy throughputs cannot be handled with any hope of uniformity of hardness. Except when an extremely heavy throughput is required, the necessary stability of temperature in the quenchant is secured by circulation and passage through a cooler. This can be done in several ways. If dealing with water, the simplest method is to use running water and allow to flow to waste. Cooling and a closed circuit, including a storage tank or reservoir, can be brought into service where scarcity or price is a prominent issue. If the storage capacity is sufficiently large, cooling might be unnecessary. With oil, however, it is imperative on the score of cost, to have a closed circuit. A simple but satisfactory arrangement is shown in Fig. 1. It will be seen that the water-quench tank, fed by running water, holds a coil through which the oil from the quench tank is circulated when quenching is taking place. A more imposing and unusual unit is shown in Fig. 2. It is to form part of a heat-treatment shop which is being reorganised and modernised. A novel feature is that the quench tank is empty except when quenching at which time, by push-button starting, an electrically-operated pump floods the tank upwards with oil at the rate of 1,550 g.p.m. The oil mushrooms over the top after flushing the work in its passage, only to be deflected downwards into the main reservoir. The oil in the reservoir is meanwhile being circulated, by a further lower velocity pump, through a flat coil submerged in the river flowing alongside the works, surely a most convenient and effective cooler. By manipulation of the appropriate valves, the cooler can be isolated and the oil pumped into a storage tank to permit cleaning of the quench chamber and reservoir. A scraper is integral with the reservoir, and by an extension to its shaft, can be rotated from the exterior to sweep scale and sludge through the manhole at the lowest point of the system.

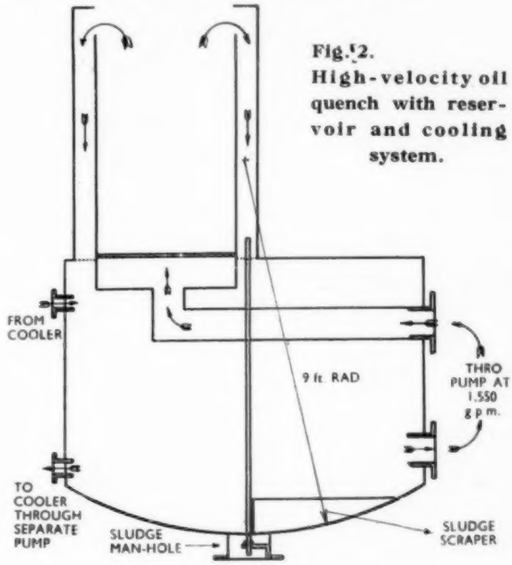


Fig. 2. High-velocity oil quench with reservoir and cooling system.

An interesting cooler is by The Visco Engineering Co. Ltd. In this the greater part of the heat is extracted from the oil by means of the evaporation of a relatively small quantity of water which is sprayed downwards over a nest of cooling tubes. Air is also blown downwards over these tubes so that both air and water are in contra flow to the oil, which enters the cooler battery at the base and emerges at the top, without coming into contact with the air or water. Since the greater part of the heat is extracted by evaporation the air volume is much less than half of what it would be with straight air blast. The cooler consists essentially of a cold-water tank on which is mounted a nest of oil-cooling tubes. Over these tubes is arranged a bank of spray nozzles and on the top of this the fan and motor are fitted. The air is blown downwards, through the cooler battery, into the cold-water tank and escapes via vertical air discharge ducts which can be taken through the roof or wall, either independently or coupled together. A nest of spray eliminator plates is fitted in each of these vertical ducts. A small motor-driven water pump keeps the water in circulation, from the base tank through the spray nozzles, in order to wet thoroughly the exterior of the cooling tubes, the surplus water draining back to the tank at the base. In practice, the loss of water by evaporation amounts to approximately 50 gallons per hour per ton of steel quenched. Make-up water is supplied through a ball valve in the water tank, which is also fitted with drain and overflow connections.

3 A.S.M. Handbook.

Occasional use is made of refrigeration to ensure the necessary cooling, but the need must be very special to justify the expense. The cooling rate required in induction surface hardening is extremely high, as only the skin of the metal is raised to a temperature from which it will harden with an adequate quench. Hence delay, or insufficient quenchant, results in failure to achieve the optimum hardness as inward conduction of heat will permit the layer of metal immediately below the surface to begin transforming to a condition softer than the martensitic. A drastic quench must, therefore, be synchronised with the cessation of heating or follow within fractional time. When the work is traversed through the inductor, or vice versa, the quench must, of course, be continuous.

In the more elaborate salt quench used for iso-thermal treatment or martempering, with the rigid limitations on temperature variations necessary therein, controlled heating and cooling are imperative. So far as is known, only electrically-heated baths have been used on any scale. Control is fully automatic, both for heating and cooling, the former principle being well known but the cooling is achieved by blowing cold air around the space allowed between insulation and salt container, whilst uniformity of temperature in the bath is secured by the use of an electrically-driven paddle agitator. A bath of this type is shown in Fig. 5. A very recent type of American iso-thermal quench bath[4] cools by flushing the work with hot salt in headers, each of which is fed by a separate pump. A motorised pump lifts the salt into a trough mounted over the separation chamber located at one end of the unit. Cold air directed on to this trough chills the salt to a temperature at which the contaminating chlorides from the high-temperature baths are "frozen" out and the still liquid nitrate salts seep back into the separation chamber and thence to the bath proper. This automatic scavenging avoids interference with the flow of work for the purpose of removing the chlorides when pollution makes it essential.

4 Ajax Electric Co., Philadelphia.

Fig. 5.—Electrically-heated and operated salt bath for isothermal treatment and martempering.

When hot saline solutions are employed, means are adopted to retain a reasonably constant temperature. Alternative methods are available for this, such as external heating by gas or internal heating by immersion heaters or steam coils. Again, automatic control may be necessary to maintain a steady temperature.

The only lead quench needing comment is that used for patenting steel wire. Whether fuel or electrically

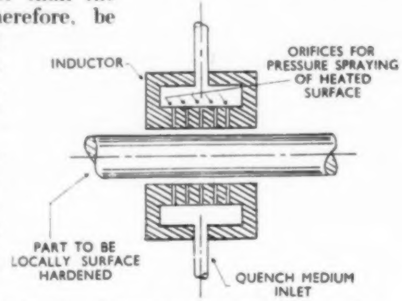


Fig. 3.—Quenching through an H.F. inductor.

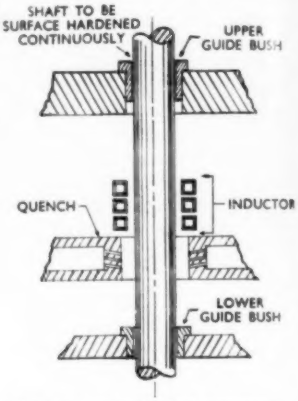


Fig. 4.—Quenching arrangement for the continuous H.F. induction surface hardening of shafts.

heated, a steady temperature is essential and this is secured in the usual way by automatic control. The continuous passage of hot wire into the lead helps materially to counteract the heat lost by radiation and conduction and the surface of the lead is also protected by a carbonaceous layer and a lid is sometimes fitted.

Quenching Practice

Desiderata in quenching number two—to obtain the required rate of cooling uniformly and to avoid, as far as possible, any distortion. The former is much less a problem than the latter, although there are many occasions when distortion is of no consequence or can be dealt with in subsequent machining operations. Conversely, it can be a most complex problem requiring the utmost ingenuity and patience to find a solution. This accounts for the many and varied specialised types of quench in common use to-day. Examples are easy to find and often well known as, for instance, the "Gleason" quenching press which handles gears, or similar circular flat symmetrical parts, by gripping them in jigs under pressure and flushing them with oil at high pressure. The orifice quenching of dies with shrouding of the outer surfaces in order to secure maximum hardness on the working face backed by tough but softer material to stand the shocks of service, is another example. We have also the spray and jet methods of quenching for hardening rolls and such like parts, whilst reference has already been made to the high-pressure quenching used in induction hardening, where water at pressures varying from a few lb./sq. in. up to 60 lb./sq. in. may be used.

Distinct from the method of ensuring an adequate supply of quenchant to the steel is the method in which a component is presented to the quench, a factor which has a marked influence on the control of distortion in certain instances. It is not out of place to assert that distortion can be averted or kept within reasonable

Fig. 6.—Quench mechanism for light alloy sections and bars with heat-treatment furnace in the background.

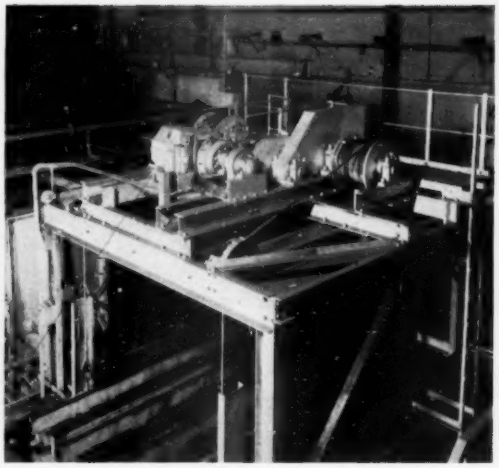


Fig. 7.—Elaborate quench mechanism and charge platform for heavy loads of alloy steel bar.

limits by annealing after rough machining, but this practice, either from ignorance of the fact or a false economic sense, seems to be reserved for occasional use on the more expensive materials such as high-speed steel. On articles such as the common needle and objects of that type, the angle of entry into the quench assumes major significance, whilst the severe distortion which can be experienced in quenching long small diameter shafts, for example, fluted loom rollers, is vastly reduced by rolling down a ramp into the quench so that they enter horizontally with a considerable peripheral speed. Distortion in many types of files is kept within bounds, and even corrected, during the quench by taking advantage of the time lag after passing the temperature coincident with the nose of the "TTT" curve for that type of steel, to withdraw from the quench, stretch in a suitable device and prevent any further movement by directing the quenchant selectively against the files during the resumed quench, in a manner known by experience to counteract any tendency to warp. The hand is employed for this purpose.

Elaborate quenching equipment is commonplace in the light alloy industry as, for example, on heat-treated extruded sections and tubes. Often the charge carrier used in the furnace also carries the charge into the quench tank. Here again vertical or angular quenching is necessary to avoid trapping steam, especially in tubes. As many of these extrusions are 30 ft. or so long, it will be obvious that whether a vertical or horizontal quench is used, the necessary quenching equipment will be most pretentious. It is not unknown for the deep vertical quench tanks used for this work, to traverse on rails in order to serve more than one furnace.

The illustration shown in Fig. 7 is of an imposing arrangement at work in a large steel works. It handles several tons of alloy steel bar in 18-ft. lengths in one charge. A charging machine withdraws the charge from the electric furnace, places it upon the platform above the quench tank, from whence it is lowered into the quenchant by the mechanism shown upon the superstructure.

The practice of bright hardening by utilising protective atmospheres and quenching directly from the interior of the furnace through a chute made gas tight by dipping into the quenchant, is reasonably well known. Illustrations appear in Figs. 8 and 9. The hardening and tempering of carbon steel strip, shown in Fig. 10,

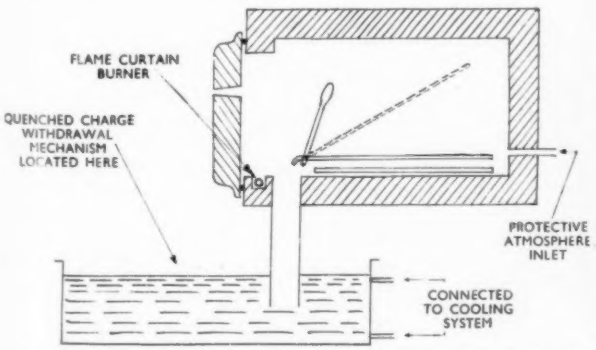


Fig. 8.—Quenching arrangement for "bright-hardening" furnace.

Fig. 9.—Operating charge-quenching gear on "bright-hardening" muffle. Note winch for withdrawal of the charge from the quench tank.

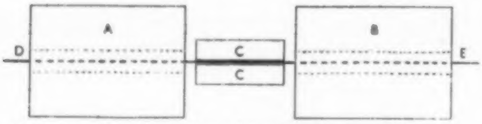


Fig. 10—Hardening and tempering steel strips continuously.

A. Hardening furnace.
B. Tempering furnace.
C. Water cooled blocks—top block "floats."
D. Strip entering furnace.
E. Strip leaving furnace to take-up gear.

provides an example of water-cooled metal blocks being used as a quench. To some extent this is analagous to employing the mass effect for quenching in high-frequency induction surface hardening where, when treating suitable alloys, the rate of heat extraction by the mass of the metal from its heated surface, is sufficient to "quench" the surface metal to a hardened state.

Conclusion

The foregoing cannot pretend to do other than touch lightly upon this interesting and important aspect of modern heat treatment. Justification may lie in bringing to a focus the inescapable fact that the seemingly simple act of plunging a piece of metal into a liquid is the penultimate or even final stage following the expenditure of much time and money in preparation. The moral is obvious.

Acknowledgments

The author is indebted to the several firms who have provided illustrations, namely, The Electric Resistance Furnace Co., Ltd., for Figs. 6, 7, 8, 9 and 10. The Electric Furnace Co., Ltd., for Figs. 4 and 5. John Holroyd & Co., Ltd., Milnrow, Lancs., for Fig. 2.

Automatic Control of Electric Furnaces for Heat Treatment

By Leo Walter, A.M.I.Mech.E., M.Inst.F.

Reliability and accuracy are the two most important considerations governing the selection of a temperature controller, but the modern trend is moving rapidly towards fully automatically operated furnaces, which, in addition to having facilities for time-temperature control, are equipped with atmosphere-, draught-, or pressure-control, etc. Some aspects of this automatic control of electric furnaces are discussed.

THIS brief survey deals mainly with the temperature control of heat-treatment furnaces, which latter range from very small units for tool-making to quite considerable sizes in the manufacture of iron and steel. The basis of automatic control of any industrial process in general is measurement and it is assumed that the reader is familiar with the fundamentals of measurement in connection with the above subject. Automatic furnace control is, then, elaborated measurement of all the process factors, mainly of furnace temperature. Measurement of a process variable produces impulses which, when magnified, introduce control action. The heated substance can be any material requiring high-temperature treatment during manufacture. The most extensive use of high-temperature pyrometry occurs in the metallurgical field and most of the temperatures encountered there lie between 300° C. and 1,600° C. Control of the higher temperature range had for a long time been performed by hand only, due to lack of robust, reliable industrial types of instruments. Once high-temperature pyrometry had reached a more advanced stage, addition of control elements to high-temperature pyrometers enabled development of sturdy pyrometer-controllers of the non-indicating, indicating and recording types.

For the higher furnace temperatures, thermocouple instruments or radiation pyrometer controllers are standard in automatic furnace control. Furnace temperature controllers are power-operated, because the small impulse developed from the temperature-detecting control element, such as a thermocouple or radiation pyrometer requires magnification to produce the final control movement. Control action may consist of the adjustment of a heavy stack damper, or the positioning of electrodes, or of electrical gear for varying the rate of heat input. The usual outside sources of power for automatic controls are electricity, compressed air, or water or oil under pressure, and sometimes combinations are used in electro-pneumatic or electro-hydraulic control instruments. The diagram shown in Fig. 1 illustrates the basic elements of any type of automatic controller, irrespective of the nature of the outside source of power, and their relation to the heat flow process. The diagram also indicates the "control cycle," whereby a chain of reactions is performed which originate in the controlled furnace and return to the furnace in the form of the control movement of the regulating unit.

Accuracy and Modes of Control

Modern furnaces are mostly of such efficient design that control can be performed within narrow limits. It should, however, be realised that accuracy of control depends on two main factors, which are inseparable, and cannot be dealt with independently. Accuracy of control is always the result of controller characteristics plus furnace characteristics. Thus, achievable accuracy of furnace control not only depends on the qualities of the control instrument, which may be "quick-acting" or "very sensitive" in one instance, and "slow acting" or "less sensitive" in another instance. The characteristics of the furnace and the working conditions determine accuracy of control to an even greater extent than instrument characteristics.

The basic rule for achieving the best possible accuracy of control is *to match the controller characteristics to the furnace characteristics*. It would obviously be wrong to apply a very responsive pyrometer-controller to a large

brick-built furnace, which requires considerable time for changes of temperature to occur, because of the residuant heat in the refractory material. On the other hand, a very small heat-treatment furnace for tools might require a more responsive thermocouple instrument, because the furnace itself has a "quicker reaction rate." Accuracy of automatic furnace control depends, therefore, on the working conditions plus the choice of the correct controller type. A third factor is the correct installation of the instrument, because the most suitable controller might fail if its installation is faulty; a suitable layout is shown in Fig. 2.

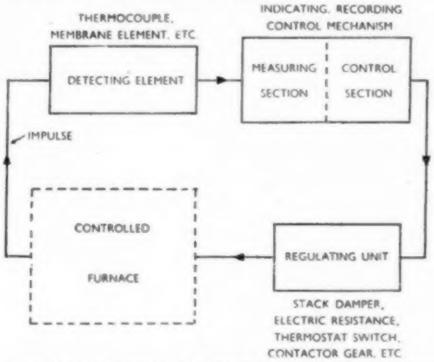


Fig. 1.—Basic elements of automatic furnace controllers.

One point should be stressed regarding accuracy of control. The user cannot expect to achieve a straight temperature line on a rectangular chart record, or a perfect circle on a circular chart. Small waves or deviations of temperature are inevitable in automatic control, because counteraction of control can only develop from a control mechanism *after* a small change of the controlled process variable—i.e., furnace temperature, has already occurred. Were the furnace temperature to remain steady—i.e., produce a straight-line temperature curve, no control action could be initiated; it would, of course, not be required if the temperature remained steady. These temperature deviations for the purpose of initiating control action will be small, if the controllability of the furnace is good, and provided that the choice of the controller type has been correct. A less controllable furnace, however, will produce more pronounced waves of the record curve in spite of using a responsive controller, because the reaction rate of the furnace might be so slow as to delay the result of the controller action considerably. The main factors influencing the accuracy of control are thus: (*a*) Responsiveness of the furnace to control action (a process characteristic), depending mainly on the time lags of reaction of the furnace related to the regulating unit; and (*b*) the way in which the latter counteracts a change of furnace temperature. This is called "mode of control," and is the decisive factor in controller design.

Basically, two main groups of control mode can be distinguished: Two-step or multi-step modes, and gradual (modulating) modes of control.

Two-step and Multi-step Mode of Control

The most common type in the control of furnaces is the "Two-position" control mode. Thermo-electrical controllers usually employ a mechanical trip arrangement, to produce either "on/off" or "high/low" control. Two position control produces only two extreme positions of the regulating unit; for on/off, they are the maximum or nil, for high/low they are the maximum and a minimum of energy input. On/off control is performed by using a thermostat switch for opening or closing the supply of electric current or of fuel to a furnace.

The two-step mode depends entirely on the *time-factor*. By lengthening the "open" periods of heat supply the average heat input is increased, and vice versa. High/low control will then allow for maximum heat input as long as the furnace temperature is below the desired value (control temperature), but will cut down heat input to a minimum, once the furnace temperature has

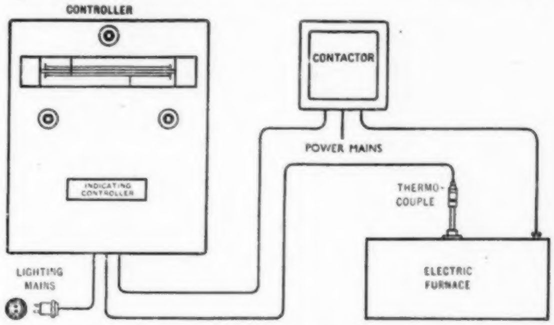


Fig. 2.—Installation layout for indicating electric furnace controller with contactor.

reached the set point of the controller. For example, three heating elements or burners are in operation during heating-up from cold, but one element is operated for running the heat load only, after the desired furnace temperature has been reached, and the controller has cut out two heating elements. The remaining element should be just sufficient for holding the furnace temperature steady by making up for heat losses from the outer furnace walls by radiation and convection, and for heat losses from flue gases, etc.

Three-position control has a "high-medium-low" rate of heat input, and the multi-position mode allows a multitude of rates of heat input to come into operation, according to the heat demand from the furnace, for example, by means of a contactor.

The basic design for two-position control is usually some form of electric thermostat switch. Fig. 3 shows the principle of potentiometer control; once the

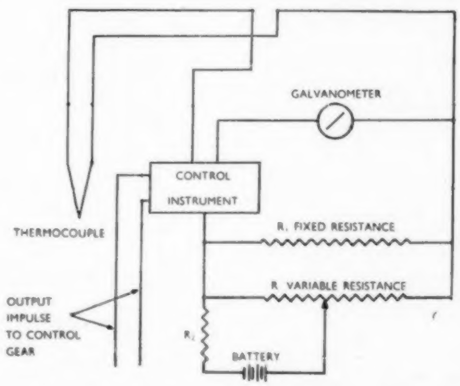
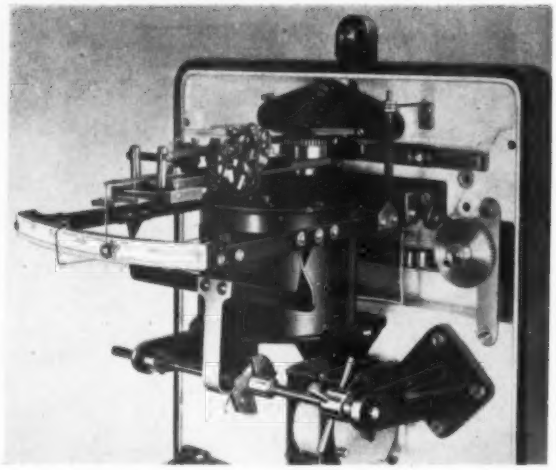


Fig. 3.—Electrical circuit for potentiometer controller.

Note.—Voltage for thermocouple is opposed by equal voltage from battery. The galvanometer is of the moving coil type and deflects if temperature deviates.



Courtesy of Elliot Bros. (London), Ltd.

Fig. 4.—Chopper-bar mechanism.

galvanometer pointer reaches the "set" temperature, the switch trip mechanism will come into action, and reduce heat flow to the desired (set) low-heat position, which can be "nil" for on/off mode, or "low" for high/low control. Two-position control is essentially "cyclic" in character, and the furnace temperature will fluctuate between an overrun and underrun. The temperature difference between the set temperature and the low temperature at which the control switch action occurs is called the "operating differential" of the control switch. It may be 1° C., or 5° C., or more, according to the desired accuracy of control. The smaller the differential is adjusted, the closer might control become but, obviously, the cycling character will be emphasised by a quick reaction rate of the furnace, and a continuous on and off movement of the regulating unit might result, which is undesirable.

This cycling of control might become critical, and develop into "hunting"—i.e., excessive erratic movement of the controller, with erratic cutting in and cutting out of the current, or of the fuel supply. Most heat-treatment furnaces have a large capacity for heat storage, which smooths out changes of temperature, and furnace temperature will neither rise nor drop too rapidly after the heat has been switched on or off. A furnace is thus less elastic to change of heat input, which is advantageous for two-position control, but not so good for the gradual mode of control, because the time lags falsify the control effect.

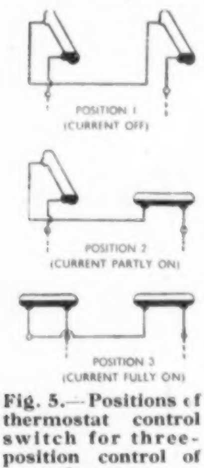
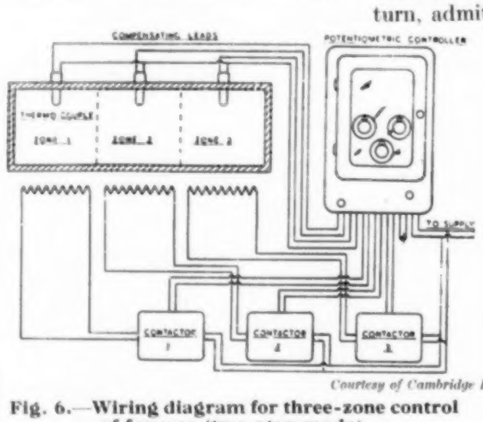


Fig. 5.—Positions of thermostat control switch for three-position control of furnace.

The selector mechanism of a furnace controller is usually sensitive to a change of 2–3° (± ½° C. for the better class instruments). In spite of this small differential, the furnace temperature is bound to over-shoot or under-shoot due to the inherent heat storage capacity of the furnace lining, which continues to dissipate heat after the heat supply has been cut out. Fig. 4 illustrates the well-known chopper-bar mechanism, used for two-position control. The instrument pointer moves a contact pointer, which is mechanically and automatically lowered, until it just touches one of the two contacts provided for high or low heat supply. This control movement might occur every few seconds, or at longer intervals, as required. If the measured temperature is below the set point, the plus contact will be closed, and heat admitted to the furnace. If the set temperature has been overstepped, the minus contact will be made, and heat flow cut out (on/off), or reduced to a minimum (high/low). Fig. 5 illustrates switch positions for the "high-medium-low" mode.

Recently the use of electronic furnace temperature controllers has come more to the foreground. The advantage of the electronic tube is that it responds very quickly to minute electrical impulses and magnifies these impulses in an electronic relay. Certain of these instruments resemble the chopper-bar type of controller in that there is an indicating pointer and a setting pointer, although no chopping mechanism is necessary. Use is made of capacitance and inductance effects for the purpose of signal generation. In the former case each pointer carries a plate of a condenser and the capacity varies with the register of the two plates. In the inductance method, the plates are replaced by coils.

A multiple on/off regulator for controlling three zones of an electric furnace is shown diagrammatically in Fig. 6. The temperature can be set independently for each zone: the contactor is operated by the driving motor of the instrument, and contacts are made every 7 seconds. In contrast, control of a small furnace can be effected by means of a contact dial thermometer, using the on/off mode of control. The diagram, Fig. 7, illustrates the wiring arrangement, the position of the unit in the oven, and the connection of the contactor. The making of contact by the thermometer pointer with the set pointer energises the contactor which, in turn, admits heat to the furnace. The position of the detecting element in the furnace is of the utmost importance in achieving accuracy of control, particularly in



Courtesy of Cambridge Instrument Co., Ltd.

Fig. 6.—Wiring diagram for three-zone control of furnace (two-step mode)

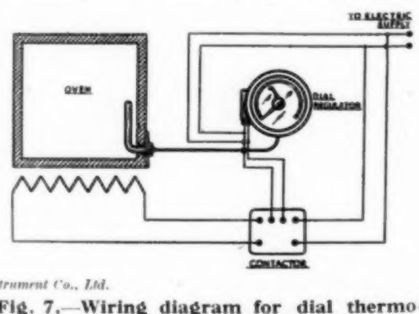
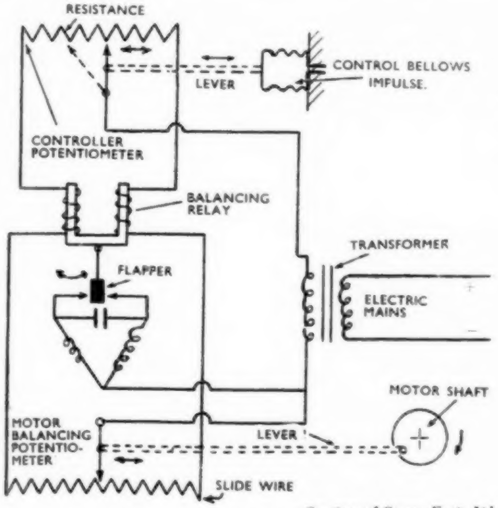


Fig. 7.—Wiring diagram for dial thermometer-regulator for controlling electric oven.

the case of two-step control. If it is situated too close to the furnace charge, for instance, the furnace brickwork will be heated to a temperature well in excess of the control temperature before the current is cut off, and the temperature of the charge will overshoot. On the other hand, a location too close to the source of heat will result in the rate of rise of temperature of the charge falling off considerably as the control temperature is approached.

Gradual Mode of Control

Many heat flow processes require a continuous control action, whereby the heat input is varied proportionately to the rise or drop of the temperature. Normally, they work upon the potentiometer principle, but when used with electrical resistance thermometers, they work on a Wheatstone bridge circuit. For working in conjunction with thermocouples, potentiometer controllers can be supplied for any voltage of the magnifying current up to 250 volts A.C. at any frequency, or for D.C.



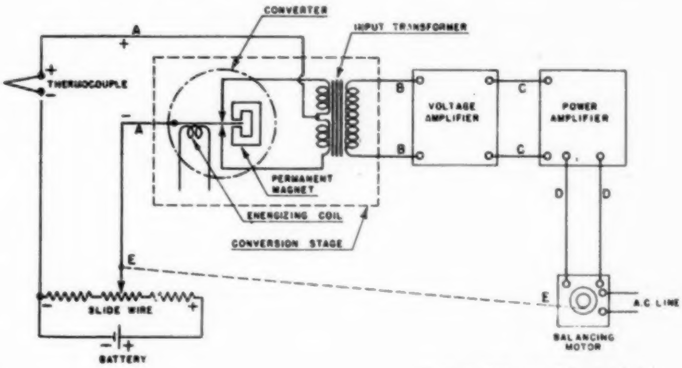
Courtesy of George Kent, Ltd.

Fig. 8.—Wiring diagram for recorder-controller of the electric type, using potentiometer slide wire.

Fig. 8 shows a proportional electrical controller, which uses a potentiometer slide-wire, the movement of which actuates a cam mechanism. A motorised power unit contains the primary Selsyn motor, the other being located in the instrument. The Selsyn motor mechanism in the instrument moves proportionately to the deviation of the furnace temperature, and causes the second Selsyn motor in the power unit to take up a corresponding position. The power unit can then be used to adjust the heat input to the furnace. The thermocouple is located between the heat source and the furnace charge, a position which causes it to react to the average furnace temperature.

Means are provided for adjusting the "proportional band" of the controller—i.e., the rate at which intensity of heat input into the furnace is varied per degree deviation of temperature. A wider proportional band (indicated on a scale on the control mechanism) produces a gentler rate of heat input, a narrower width of band allows a greater rate of heat input per degree of change of furnace temperature.

Another phenomenon which should be explained here is the "offset" of temperature. This is the wandering of the set temperature in the case of sudden disturbances of the heat load. For example, if the furnace load is suddenly doubled, the temperature will fall in spite of proportional control, and establish itself at a new, lower set point. If the furnace load is halved, a higher set point will establish itself. To avoid this the controller mechanism will have to be reset, either by hand or, preferably, automatically where frequent and heavy changes of heat load occur. Controllers providing this reset correction, use "reset mode" of control. These stabilised controller types have to be used for the larger industrial heat-treatment furnaces. One method of achieving reset control is to utilise the deviation of furnace temperature (new set temperature from original set point) to cause the circuit to the power unit of an electrically-heated furnace to move a resistance to the furnace heating elements in the right direction and at the right amount to correct the offset, thus re-establishing the original temperature setting.



Courtesy of Honeywell-Brown, Ltd.

Fig. 9.—Wiring diagram for electronic potentiometer-controller.

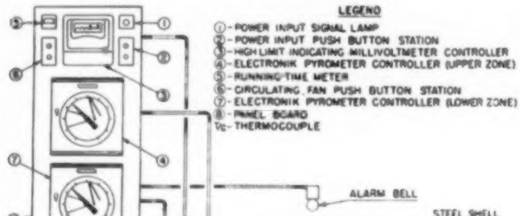
The electronic principle can be conveniently applied to the gradual mode of control. The design of the controller is based on the movement of a vane interposed between two oscillator coils in an electronic circuit. The vane is moved mechanically from an instrument pointer and, having practically no friction, responds readily to minute changes of furnace temperature. Maximum presence, or complete absence, or intermediate intensity of oscillation of the field between the two coils is varied by the position of the vane. This in turn determines the flow of current reacting on an electronic amplifier tube, the amplified electric impulse reacting on an electrical relay. The relay mechanism admits an amplified electric current of the right intensity to a power unit, which positions the furnace electrodes, or rheostats, etc., thus varying the rate of heat intensity automatically, as desired.

Further progress in instrument design has been made by introducing continuous detection and rebalancing by a potentiometer, illustrated in diagrammatic form in Fig. 9. It works without galvanometer or chopper bar, cams, gears, levers and clutches. Only two moving parts are used up to the point where the slider and instrument pen are moved. These parts are a reed in the converter, in which the minute e.m.f. from the thermocouple is transformed, and the motor armature.

The electronic tube reduces the instrument lag, and allows the use of a narrow proportional band, with better hold on control.

Typical Applications

Electrically heated multi-zone furnaces for normalising purposes are being successfully controlled by means of potentiometer-controllers. The temperature controllers are mounted on a panel and each instrument controls heat input to one furnace zone. Two instruments are indicating and two are strip-chart recorders, all working on the on/off control mode. Each controller operates a contactor with electrical gear for switching the current on or off.



Courtesy of Honeywell-Brown, Ltd.

Fig.—10. Automatic control of gas-carburising furnace.

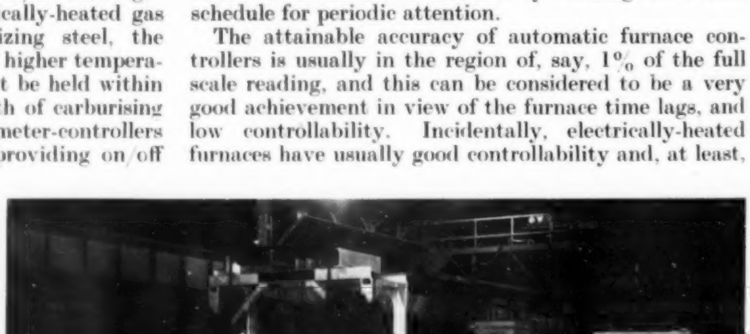
Fig. 10 illustrates diagrammatically on/off and high-temperature limit control of an electrically-heated gas carburising furnace. In gas carburizing steel, the process can be speeded up by the use of higher temperatures, but the desired temperature must be held within close limits, otherwise variation in depth of carburising would occur. Two recording potentiometer-controllers are actuated by thermocouples, thus providing on/off control of the electric heating elements in the respective zones. A third thermocouple, mounted midway in the retort, provides limit control. Any excess temperature automatically cuts out power and rings the alarm bell; signal lights are also used, as shown. The carburising cycle can be set on a timing mechanism. When the correct carburising temperature has been reached, the timer is energised and automatically stops the process after a predetermined time interval.

As an example of efficient automatic temperature control, Fig. 11 illustrates an electrically heated two-zone furnace with an indicating temperature controller for each zone. On the same instrument panel is also fitted a two-point temperature recorder within view of the furnace operator. Behind the instrument panel are a transformer and a contactor panel, which are easily accessible for inspection and servicing. The cleanliness connected with the use of electric furnaces makes the installation of instrument panels near the furnace possible, and allows the use of standard types of electrical controllers of the indicating or recording type. Where recording instruments with indicating scales are fitted further away from the furnace, the use of large instrument dials with bold figures and pointers is advisable, to enable the furnace operator to see them from a distance. Under certain conditions, telemetering methods will have to be used, where the control panels are at a distance from the controlled furnaces, and it is desirable that the furnace operators should have indicating instruments in front of them.

The Choice of Instrument

The question of the choice of instrument type for electric heating furnaces can best be solved by the closest co-operation between the furnace engineer, the plant supervisor, and the control expert. Whether control instruments are of the potentiometer type or of the millivoltmeter type depends on local circumstances and on working conditions. Potentiometer instruments are generally considered to be more accurate, as the galvanometer is independent of the indicator pointer or recorder pen, because it works independently from them and does not put any strain on the mechanism for control. Potentiometer controllers are, however, higher in first cost than the millivoltmeter type, and are also more elaborate. Whichever type is favoured they should be in the care of skilled personnel and preventive maintenance should be the rule. Although it is obvious that proper care should be given to measuring or controlling instruments at regular intervals, by inspection and overhaul, this is not always carried out in practice, and many unnecessary instrument breakdowns occur, which would have been avoided by working out a time schedule for periodic attention.

The attainable accuracy of automatic furnace controllers is usually in the region of, say, 1% of the full scale reading, and this can be considered to be a very good achievement in view of the furnace time lags, and low controllability. Incidentally, electrically-heated furnaces have usually good controllability and, at least,



Courtesy of G.W.B. Electric Furnaces, Ltd.

Fig. 11.—Control panel on two-zone billeting furnace, electrically heated.

it is equal to the best controllability achieved with gas- or oil-firing.

General Aspects

The number of instruments supplied with an electric furnace varies with make, purpose of furnace, and with the demand for automatic furnace action on the part of the user. In general, the complete instrument cubicles are supplied by the furnace builders, wired and fitted with instruments, pilot lamps, relays, time switches and labels. Automatic timers on electric furnaces allow the furnace to start operation by pushing a button, and the furnace will then be automatically stopped after a set time interval has elapsed. Heat-treatment furnaces can be equipped with three-position-control timers, producing high/medium/low heat input by means of special mercury-vacuum switches and relays, as shown diagrammatically in Fig. 12. The cubicles containing the contactor gear are usually floor-mounted near each furnace, or are part of the instrument panel. Contactor gear panels consist of a main isolator with mechanical and electrical interlocking devices, which ensure the correct sequence of operations, and safeguard working in general. Each contactor has usually a solenoid overload protecting device, with pilot lamp, relay and fuse, etc. Where air movement is provided for, each fan for forced circulation has electrical gear for interlocked automatic fan operation, which also includes a limit relay for cutting out the fan motor in the case of maximum furnace temperature having been reached.

The common type of temperature detecting control elements are thermocouples, with compensation leads included. They are of robust and heat-resisting design with adequate protecting sheaths, to withstand temperature and furnace atmosphere. Iron-Constantan types generate a voltage of about 6 m.v. per 100° temperature difference between hot and cold junction. Chromel Alumel couples generate 4·00 m.v., and platinum/platinum-rhodium couples 1·35 m.v. Where millivoltmeter instruments are applied, they should have an internal resistance to compensate for errors from the lead resistance and the leads should be made from compensating cable.

Because of the frequency of switching, only the best design of contacts in the contactor gear is good enough, if reliability of control is to be assured. The most frequently used contactor type has a clamping arm and works like a chopper bar mechanism. For some furnace types, star-delta switching can be applied with advantage, especially for lower temperatures and for lighter than average loads. The rating of the furnace is thereby reduced by approximately one-third.

The electric heating elements are, of course, of paramount importance, and various types, often covered by patents, have been developed by makers of electric furnaces. Elements can be strips, or heating coils, made from special nickel-chrome alloys or other suitable materials. Heating elements must be just as well protected against over-temperatures, as the refractory material and roof of the furnace, and over-temperature protective devices have to be provided for. They can be fusible types, or variable type regulators for limit control, and they cut off the current in case of danger.

Time-temperature control has already been mentioned, but programme controllers can be applied for producing any desired heating cycle, for example, for producing a heating-up curve, a holding temperature period, and a cooling down period at will. Engineered furnace control can then add automatic furnace atmosphere control, draught- or pressure-control, etc.

In conclusion, the writer would like to state, that the modern trend in furnace design and operation is moving rapidly towards making the industrial furnace a reliable, fully automatically operated machine, which runs at top efficiency all the time. Electrical resistance heating for furnaces is particularly suitable for fully automatic operation, and it can be visualised that electric furnaces of the future will have automatic gear as standard equipment for any process variable, such as temperature, draught, etc., and also for the mechanical handling of the material treated.

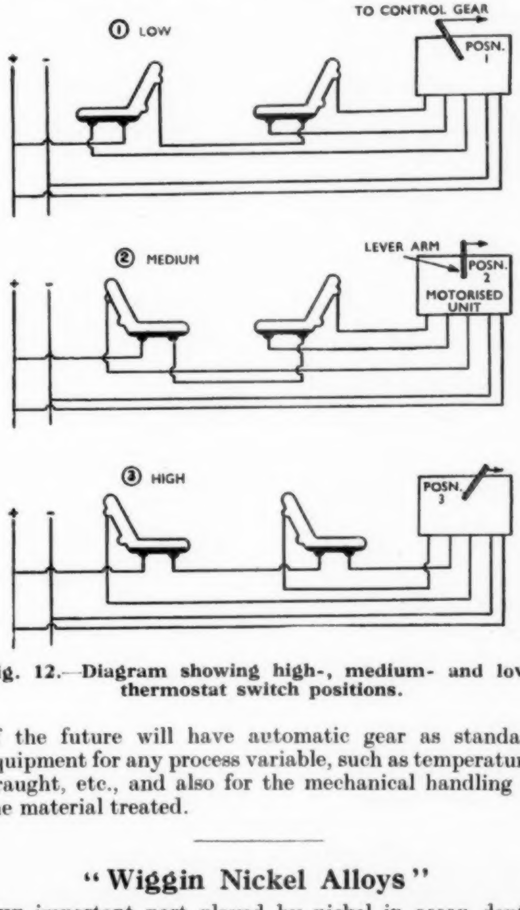


Fig. 12.—Diagram showing high-, medium- and low-thermostat switch positions.

"Wiggin Nickel Alloys"

THE important part played by nickel in ocean depth sounding equipment is demonstrated in an interesting and fully illustrated article in a recent issue of Henry Wiggin's "Wiggin Nickel Alloys."

Shorter articles deal with the use of Monel in cannery pipelines, bottle-filling machinery, pumps, rotary vacuum filters and electro-steam equipment. A description of the use of "K" Monel in reconditioning pumps for high viscosity, corrosive liquids is of particular interest.

A new use for Inconel in medical equipment is described and the makers' experience with continuous annealing furnace tubes in this alloy is briefly outlined.

The "Brightray" series of electrical resistance materials are listed and the factors which should be considered in choosing the correct material are explained.

Mangonic, a nickel-manganese alloy, and Ferry, a nickel-copper alloy, are also the subjects of short articles.

Recent Heat-Treatment Furnace Installations

Some Typical Examples

Progress in the design and construction of heat-treatment furnace equipment continues on a considerable scale and furnaces and equipment of a very high order have been installed during the past year, many of which have been designed for the heat treatment of particular products on a continuous or semi-continuous basis, but standard equipments for more general work are increasingly employed. A few typical examples are briefly described.

MANY operations or processes are necessary to convert a metal or alloy into such a form or condition that it is capable of useful service. Of these operations, the most important is heat-treatment, since it is a vital operation in the fabrication of most metal parts and in conferring upon the material certain specified properties. So important is this operation of heat-treatment that its study may often be of more practical value than the search for new alloys; further, the useful effect of the addition of new elements is often entirely dependent on a heat-treatment, without which the result would be of little interest.

In a broad sense, the term heat-treatment embraces all processes which involve heat by which the physical or mechanical properties of metal and alloys are affected. In this article, however, more particular attention is directed to equipment in which the heat-treatment operations are designed to modify the structure and constitution of the metal by controlling the heating and cooling conditions under which changes in the solid state occur. Considerable attention has been given to the control of heating and cooling and great advances have been made in recent years. It has long been appreciated that control is not only concerned with the use of modern appliances developed to assist in maintaining a uniform temperature in the furnace chamber, but in controlling the time and rate of heating and cooling, and the atmosphere surrounding the material undergoing treatment.

In carrying out the operation much depends on the equipment installed; furnaces and equipment of a very high order are now available which can reasonably be classed as precision tools. With these modern appliances heat-treaters have greatly advanced in their art, but even with the best equipment the increasing demand for materials with widely different properties calls for operators of considerable skill and experience. Assuming that the material to be heat-treated meets the appropriate specification and the heat-treater is an experienced man, the most suitable type of furnace for a given operation depends upon many factors, but the value of the result desired is of primary importance in determining the type. The cost of the heating medium employed, temperature and atmosphere control, and other phases in heating operations, are really incidental to the main consideration which involves the quality of the finished product and its overall cost. Thus, when making a choice it is important to bear in mind the need for producing a high-grade product at low cost, using that form of heating medium and that type of equipment which will give these results under the particular conditions that operate in the works at which the installation is contemplated.

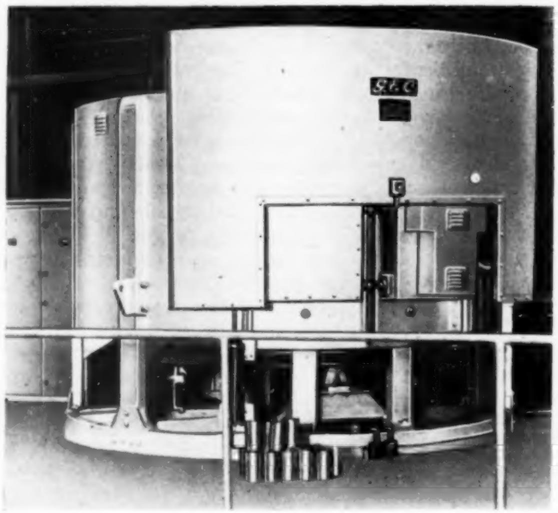


Fig. 1.—A G.E.C. 175 kW. rotary-hearth furnace for heating alloy billets prior to extrusion.

The choice is frequently a compromise between that which is considered to be the best in theory and that which, when viewed with the conditions associated with the particular case, is practical.

In assessing the relative importance of the many factors involved, local conditions play a part, but the guiding principles are concerned mainly with reliability and flexibility of output and ease of control. For mass production the duty demanded of heat-treatment furnace units may, and frequently does, amount to a very precise and clearly defined treatment and output. The allowable margin to cover contingencies and unknown factors is much reduced in furnaces specially designed for the treatment of particular products, but a fair measure of flexibility of output and range of temperature is demanded in many types of general purpose heat-treatment plant.

Very few heat-treatment furnaces burn coal, but an economical and satisfactory way of using coal is by feeding the coal automatically to a fire below the chamber being heated. In this process of gradual heating, volatile and smoke-forming gases are liberated and burnt completely by the incandescent part of the fire. Feeding the fire by means of a mechanical stoker is applied in many cases for heating, and in a number of cases it is being used as a heating medium in carburising furnaces. In the majority of instances, however, gas, oil or electricity constitute the heating medium; the

gas used may be producer, coke oven or town's gas. Each have their advantages and disadvantages, but the quality and cost of the treated product should determine the choice.

During the past year or so developments in heat-treatment furnaces have largely centred around the demand for continuous heat-treatment processes. Such processes as hardening, annealing, normalising, brazing, etc., are now commonly carried out, with or without the use of controlled atmospheres, in furnaces of the roller hearth, rotary hearth and mesh-belt types, even where long heating cycles are required. The intermittent pusher-type furnace, where the charge is progressed through the furnace in stages, is also being used for some processes in preference to the batch furnace. The application of induction heating to heat-treatment processes has also caused developments in designs of suitable equipment for particular operations.

Heating Furnaces

Although this review is primarily concerned with heat-treatment equipment, in which the object is to confer certain properties on the material treated, many interesting recent furnace installations for heating slabs, ingots and billets show changes in furnace technique and design resulting either from the stringent metallurgical specifications now insisted upon or from a desire to further increase production. The rotary hearth furnace, for instance, not only facilitates continuous and rapid production but makes this possible in the minimum of floor space. A typical 175 kW. furnace of this type is shown in Fig. 1, several of which have been supplied for the heating of alloy billets in a controlled atmosphere prior to extrusion. Maximum operating temperature is 850° C. A new G.E.C. billet heating furnace of the same type is rated at 210 kW. and provides for a maximum operating temperature of 1,100° C. This furnace has a mean diameter of 5 ft. 9 in. and a motor driven, variable speed hearth 16 in. wide. The doors, which close automatically, are pneumatically operated and controlled by foot pedals to prevent them being accidentally left open. Burnt town's gas provides a suitable atmosphere for the bright treatment of the charge and a gas screen is formed across the openings of the doors during loading and unloading.

An interesting design of billet heating furnace is that shown in Fig. 2. It is typical of the gas-fired walking beam furnaces designed by Birlec, Ltd., and the furnace shown is installed at Yorkshire Copper Works where it is used for heating copper billets for piercing. Probably the most drastic change in furnace technique is that resulting from the use of induction heating, a notable example being the heating equipment* supplied jointly by Birlec, Ltd. and the Electric Furnace Co., Ltd., installed in the new forge of John Garrington & Sons, Ltd. In this forge, 12 of the latest type of forging presses have been installed for the mass production of repetition forgings. The presses, which vary in size, are capable of large outputs, provided a steady supply of billets suitably heated to a uniform temperature is available. The use of high-frequency induction heating has fulfilled all requirements. Twelve heaters are installed and, since the output and size of the billets to be heated vary with different sizes of press, six of the heaters each have a rating of 150 kW. with a hearth diameter of 4 ft. 6 in.; three are rated at 250/300 kW. with 5 ft. 6 in. hearths; two at 400 kW. with 5 ft. 6 in. hearths; and the largest is rated at 800 kW. with a hearth diameter of 7 ft. 6 in.

Stress-relieving Furnaces

A special heat treatment is necessary for the removal of stresses from components and accurate control of temperature is an essential requirement for such operations. A typical example of a furnace designed for this purpose is the town's gas-fired bogie-type furnace shown in Fig. 3. It was designed and built by G. P. Wincott, Ltd. for the stress-relieving of large gun turrets up to a temperature of 650° C. This furnace has a heating chamber 24 ft. wide, 10 ft. 6 in. high and 23 ft. long; it is designed for full recirculation and is fitted with automatic temperature control equipment. Several pusher-type stress-relieving furnaces have recently been built and installed by Brayshaw Furnaces & Tools, Ltd., an interesting example of which is shown in Fig. 4. This is town's gas fired and is designed for stress-relieving cylinder blocks. The furnace shown, which has preheating and main heating zones with a total length slightly over 15 ft. and a cooling zone about 10½ ft., is capable of dealing with four cylinder blocks and heads

* *Metallurgia*, 1949, Oct., pp. 332–334.

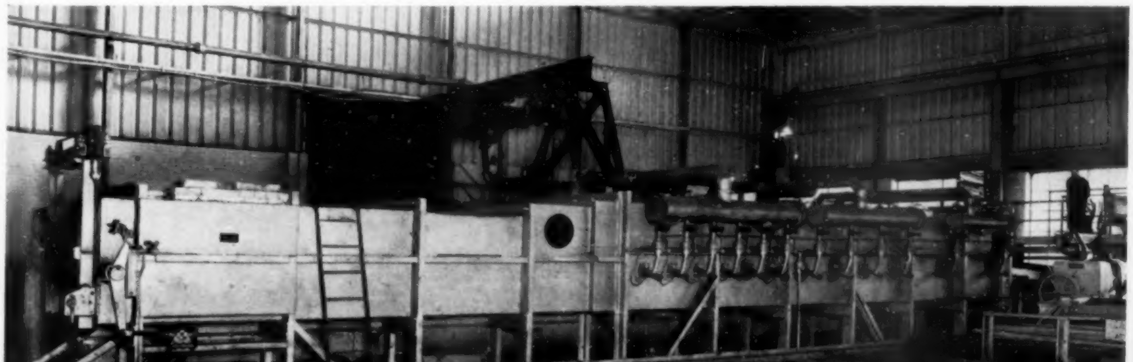


Fig. 2.—A gas-fired walking beam furnace by Birlec, Ltd. for heating copper billets for piercing at Yorkshire Copper Works, Ltd.

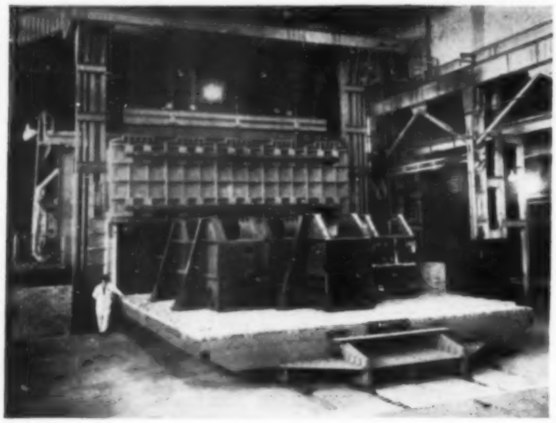


Fig. 3.—Town's gas-fired bogie-type furnace by G. P. Wincott, Ltd., for stress-relieving large gun turrets.

per hour, which represents an output of about 1,520 lb. of work.

Town's gas or clean producer gas have been more generally used for firing furnaces for stress-relieving purposes because it has been claimed that precise control of the comparatively low temperature of 650° C. is more easily obtained, but oil-fired equipment is being used with complete success. Equipment of this type has been designed and built by The Dowson & Mason Gas Plant Co. which has given very satisfactory and economical results using a heavy fuel oil.

Carburising Furnaces

Considerable attention has been given to the use of gas as carburising medium and quite a number of installations are now working successfully which incorporate the Wild-Barfield patented process. This process employs "prepared town's gas," that is raw town's gas from which CO_2, O_2 and water vapour have been removed; together with the principle of employing an active carburising period and a diffusion period. By this means carburisation at the maximum rate is achieved, with complete control of the depth and type of case required. The entire equipment is supplied by Wild-Barfield in two models known as the HWR and LWR types.

The HWR type employs a heavy walled retort into which work on jigs is charged cold, the entire retort being placed in the carburising furnace, from which the retort is removed for controlled cooling. This type is being used for the alloyed carburising steels, such as En 37, 38 and 39. It is made in four standard sizes, the work space available being:

	in.	in.	in.	in.
Diameter	12	16	20	24
Length	22	30	40	48

Sizes outside this range have been built and a gas-carburising installation, with work space of 400 cu. ft., is at present under construction. A typical layout of this type of equipment is shown in Fig. 5.

The LWR type, a typical layout of which is shown in Fig. 6, employs a light walled retort which is permanently in the gas-carburising furnace. The work to be carburised is loaded on jigs and these are lowered into the furnace at temperature. The retort door also acts as a furnace door, being actuated hydraulically and clamped down by quick operating clamps. At the expiry of the correct time at temperature, the load jig is removed, either to a cooling pit or to direct quench. The standard sizes of this type are the same as those for the HWR type, but sizes outside this range can be supplied.

Improved carburising results are being obtained by the Homocarb method following the introduction of modifications to the equipment of The Integra Co., Ltd. A natural cooler is now included with the standard equipment which enables the load to be cooled, at the end of the soak, in the furnace, from the carburising temperature of about 900° C. to a transfer temperature of about 760° C. In this way cooling can be effected rapidly while the load is protected by the Homocarb atmosphere and transfer on a falling heat can be made safely, either to a cooling unit or to a quench tank. An ammonia flowscope has also been incorporated in the

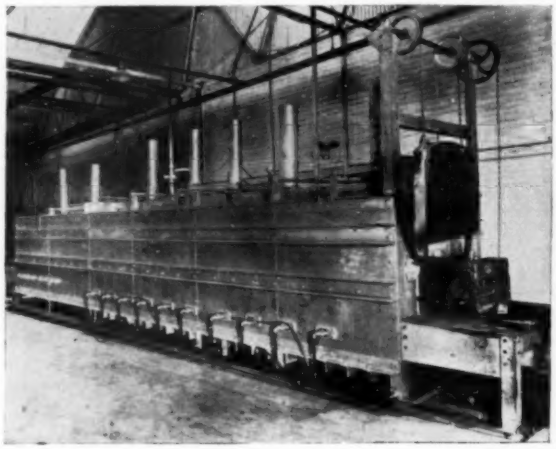


Fig. 4.—A Brayshaw gas-fired cylinder block pusher-type stress-relieving furnace.

design permitting the equipment to be used for gas cyaniding. Control of the composition of the cyaniding gas in this method is obtained by means of two controls on the furnace panel. The fluid, which provides the carburising gas, is pumped into the furnace at a controlled rate governed by the setting of the flow setter. When the fluid enters the furnace chamber, it becomes a rich carbon gas, to this is added ammonia gas from an

Fig. 5.—Typical layout of a Wild-Barfield gas-carburising equipment, HWR type.

ammonia tank, the rate of addition being controlled. The equipment incorporating these improvements is shown in Fig. 7.

The modern method of gas carburising, for which only a few of many types of equipment are shown, is a vastly improved procedure. The parts to be treated are loaded into a gas-tight chamber and heated to temperature in a neutral atmosphere ; when the whole charge is uniformly heated, a carburising gas is admitted and fed continuously until the required case depth is obtained. The process shown, is quick and economical, and permits precise control.

Salt Baths

Case-hardening and other heat-treatment operations are being successfully performed in salt baths. Indeed, in one design of plant designed by Imperial Chemical Industries, Ltd. a complete cycle of heat-treatment operations is performed. In it the work is suspended on jigs or wires and placed on a conveyer which runs across all the stages of the heat-treatment operation, including preheating, cyanide bath treatment, quenching, washing and drying. Transfer from one stage to the next is by automatically-operated arms.

Fig. 6.—Typical layout of a Wild-Barfield gas-carburising equipment, LWR type.

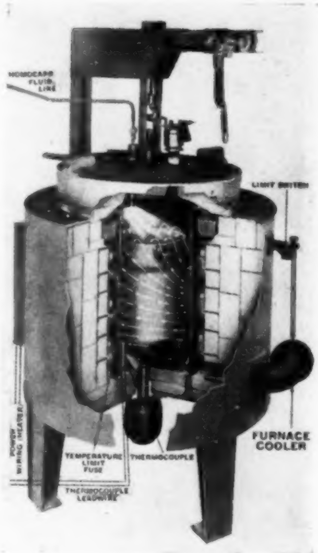


Fig. 7.—The Homocarb equipment of The Integra Co., Ltd.

Considerable progress has also been made by the Efco isothermal heat-treating process involving the use of quench baths. The process involves heating the charge to cause constituents of the steel to go into stable solution, then quenching at a selected cooling rate in a salt bath at an elevated temperature until transformation is substantially completed. The process includes austempering, martempering, cyclic annealing and other processes involving an interrupted quench. Successful control of physical properties by the use of this process is dependent upon holding the quench bath at a constant temperature. With the work transferring a great amount of heat to the bath, the quench bath must be capable of absorbing and dissipating the heat to avoid temperature build up. In order to maintain the desired temperatures accurately a special type of the isothermal quench furnace is equipped with resistance type immersion heating elements for austempering, martempering, quenching and bright annealing. Surrounding the exterior of the bath in this Efco type is an air chamber in which a controllable volume of air is caused to flow. A temperature rise of 1° C. above the control setting is sufficient to actuate this air cooling system. Similarly, the heating system prevents temperature drop below the control point. This control of heating and cooling maintains the

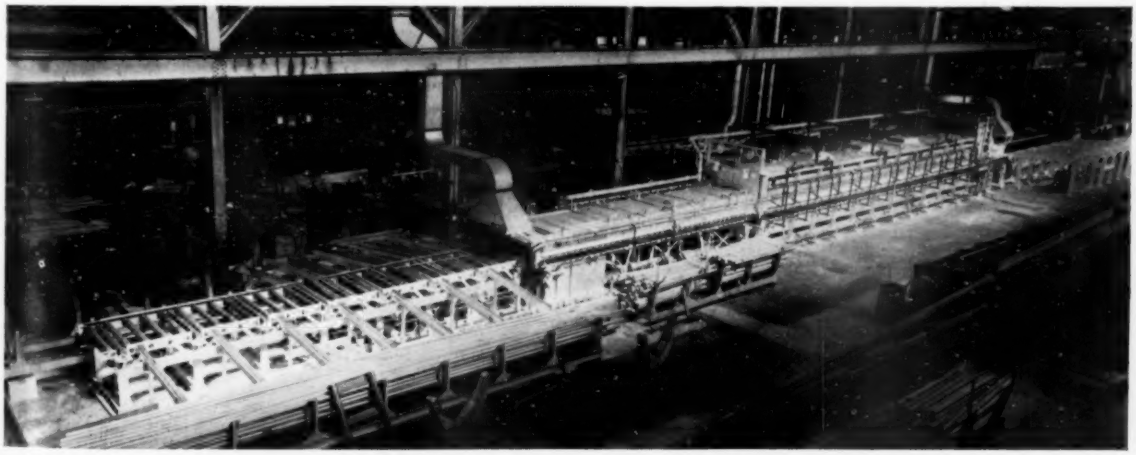


Fig. 8.—Typical of a new roller-hearth furnace in course of construction by Stein & Atkinson, Ltd., for the continuous annealing of a wide variety of non-ferrous tubes.

Fig. 9.—A G.E.C. 50 kW. batch-type furnace used for annealing silicon iron stampings. Part of the charge can be seen on the right.

bath temperature within 1° C. of any desired quenching point.

A midget type of Efco-Ajax-Hultgren electrode salt bath, incorporating the working principle and advantages of the larger design of this type of salt bath, is rated at 6 kW's, and is suitable for connection through a stepdown transformer to a 200–250 volt single phase supply. The working dimensions are 4 in. diameter by 6 in. depth of salt. Cutters up to 3½ in. diameter and tools up to 4½ in. in length can be treated. When this midget type is to be used for a variety of heat-treatment processes it is advisable to have a spare pot. For high-speed steel hardening and neutral hardening a refractory lined pot is used; while for carburising, tempering, nitriding, etc., a metal lined pot is used. In the original design the electrical equipment was located immediately above and behind the pot. After operating about 30 of these midget salt baths, it has been found preferable to have the control gear at the side, in which position it is more accessible and the fumes from the salt bath do not affect the instrument.

Annealing and Normalising

Fig. 8 is typical of a new roller hearth furnace now in course of construction by Stein & Atkinson, Ltd., for continuous annealing a wide variety of non-ferrous tubes. The furnace is town's gas-fired in two zones, and the burners are of a special " pepper-box " type giving a homogeneous atmosphere throughout the whole furnace chamber. The ratio of air to gas is controlled by a Foxboro ratio controller so that the normal desired annealing atmosphere of a slightly reducing character is obtained. The furnace is equipped with long charge and discharge roller tables, on the latter of which there is a hydraulic tilting gear actuated by Vickers-Detroit oil-hydraulic gear of Stein & Atkinson manufacture.

The tubes are charged into the furnace through a specially constructed vestibule with asbestos screens arranged on an adjustable cover; provision is made for renewal of individual screens without losing atmosphere from the furnace. The tubes pass first into the preheat zone on heat-resisting alloy rollers carried in water-cooled ball bearings, thence into the temperature-equalising zone, there being adjustable and shrouded doors at either end of the furnace proper. Following the heat chamber there is a slow cool, and then a quench chamber with weirs and a controlled recirculation of the quench water. Finally, there is a discharge vestibule generally similar to that at the charge end.

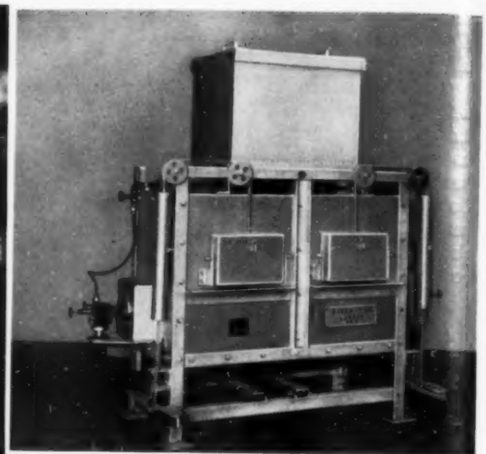


Fig. 16.—A double-doored oil-fired furnace by Kasenit, Ltd., for the heat treatment of springs.

The furnace, which has an output rated at 2–3 tons per hour, depending on the type of tube and treatment required, is heavily insulated and has a steel gas-tight casing with the roof platework carried in seals. Additional to the burner system, there is a prepared atmosphere unit supplying gas to the furnace for making-up waste gas losses from the end vestibules. This ensures that a positive pressure is maintained in the furnace at all times even on maximum burner turn-down, or when large diameter tubes are being handled. Full automatic control is also incorporated, there being, in addition

Fig. 10.—Town's gas-fired bogie furnaces by G. P. Wincott, Ltd., for the heat treatment of alloy steel.

to the Foxboro ratio control already mentioned, a Kent air-operated temperature controller to each of the two zones. Water quenching and atmosphere gas cooling are controlled by Negretti & Zambra gear. Considerable attention has also been paid to safety equipment in the event of failure of one or other of the various services.

The furnace rollers are all driven by a continuous chain, variation in speed being remotely controlled by an electrically-operated speed change on a P.I.V. gear. On the charge and discharge tables certain rollers adjacent to the furnace are driven, the remainder idling. Hand rotation gear is included to safeguard the hot rollers in the event of a power failure.

The furnace with its charge and discharge tables is 150 ft. long and the width inside the heat chamber is 3 ft. 6 in. All controls for the furnace and the prepared atmosphere unit, including safety equipment, also the remote roller speed control with its indicating equipment, are grouped on a panel adjacent to the charge end of the furnace. The experience on many similar furnaces built in the U.S.A. by Surface Combustion Corporation has been incorporated in many of the design details.

For many applications, where a particularly long heating cycle is required, or where a long carefully controlled cooling cycle is an important part of the heat-treatment process, the use of a continuous furnace may not be justified and batch furnaces satisfactorily meet requirements. An interesting batch type furnace with a rating of 50 kW., is shown in Fig. 9, where it is in use for the annealing of silicon iron stampings, and to provide an even layer of adherent oxide. The stampings are loaded on trays and moved into the furnace on roller tracks. A single charge consists of 9,600 stampings, the heating and long carefully controlled cooling cycle is carried out in a controlled atmosphere provided by a G.E.C. controlled atmosphere plant.

Two town's gas-fired bogie furnaces installed in Sheffield for the heat treatment of alloy steel are shown in Fig. 10. They are fired by low-pressure premixing type burners using air preheated by metal recuperators which are incorporated in the top structure of the furnace. Designed and built by G. P. Wincott, Ltd., most furnaces of this type are now fitted with fully floating temperature control equipment and furnace pressure control. Where heating cycles have to be reproduced accurately, programme controls are usually installed.

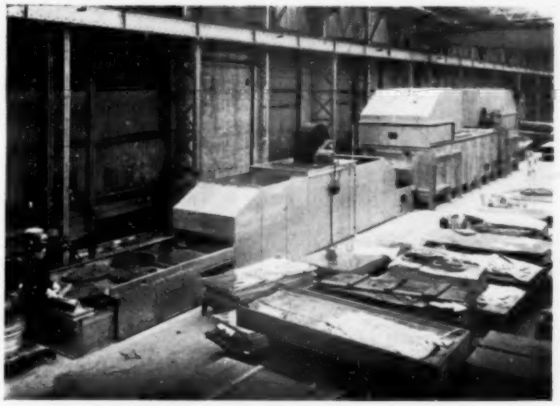


Fig. 11.—A continuous "flash" annealing furnace for aluminium and aluminium alloy sheets and circles by Stordy Engineering, Ltd.

The urgent demand by many users of aluminium and aluminium alloy sheets and circles for materials of close-grain structure and greater ductility has widened the scope of plant designed to give these physical characteristics and such a plant, designed by Stordy Engineering, Ltd., has been put into operation. It is a continuous "flash" annealing furnace which enables sheets and circles to be heated to annealing temperatures in 2–3 minutes to give recrystallisation of the structure of the material and elimination of rolling line without allowing time for subsequent grain growth.

The plant, which is shown in Fig. 11, is continuous, handling single sheets up to 5 ft. 6 in. wide and circles down to 5 in. diameter at the rate of 1 ton per hour and consists of a loading conveyor interlaced with the furnace conveyor which is interlaced with the cooling conveyor which finally is interlaced with the unloading conveyor. Each conveyor consists of a series of ropes tensioned and supported to present a system adapted to conveying and transferring the work. This transfer of the work from one section of the conveyor to another is exceptionally smooth and special attention has been given to all

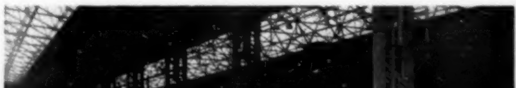


Fig. 13.—A radiant gas-fired tube annealing furnace by Birlec, Ltd., for copper tubes in lengths and coils at Yorkshire Copper Works, Ltd.

Fig. 12.—Open-fired type furnace by Stein & Atkinson, Ltd., for annealing non-ferrous tubes.

Fig. 14.—A bright hardening tilting-hearth furnace for small parts difficult to clean.

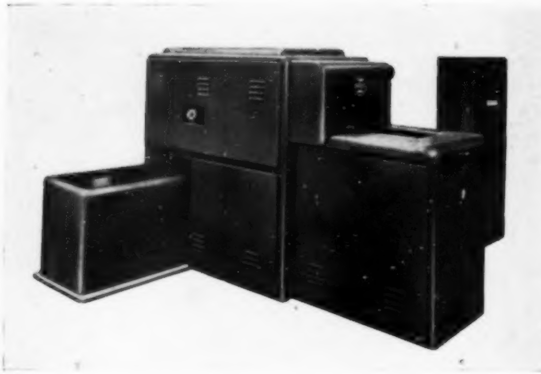


Fig. 15.—A Birlec shaker hearth conveyor furnace for the continuous bright hardening and tempering of small steel components.

conveyors to avoid marking of the polished finished work; in particular the loading and unloading conveyors have non-metallic ropes and the furnace and cooling conveyors have specially constructed ropes and fasteners with individual tensioning to each rope.

Air circulation is adopted, two large volume centrifugal type high-temperature fans disposed towards each end of the furnace supply air through the heater batteries into two sets of distribution ducts from which the air is directed on to the work. There is one heater battery to each circulating system and each battery is subdivided into lower ratings, but the total loadings of the batteries are unequal. Two control systems and contactor gear govern the operation of the furnace and preselective switching of the various ratings is provided. The cold "load" of the entering sheets is compensated by heavier rating of the heater battery at the ingoing end. Both heater batteries are entirely self-contained and can be lifted out of their seatings and lowered onto the floor for inspection and provision is made also for inspection of the batteries in position, either when the furnace is hot or cold.

For the bright annealing of metals, particularly steel strip and wires where a full annealed deep drawing quality is required G.E.C. vertical cylindrical furnaces continue to give every satisfaction. Recent installations have included a 120 kW. furnace of this type for the spheroidising of carbon steel wire. It is equipped with three charging pots each having a loading space of 40 in. (diameter) by 48 in. deep. A circulating fan fitted in each pot head permits the use of a lower temperature gradient. These vertical cylindrical furnaces are available up to 4 ft. 4 in. diameter and 11 ft. deep to take charge weights up to 11 tons.

During the past year two modern precision heat-treatment furnaces by Stein & Atkinson, Ltd., for annealing non-ferrous tubes have been installed in the North-Midlands. One of these furnaces is shown in Fig. 12. They are of the open-fired type, each being designed for an output of 2¾ tons per hour, and have an effective length of 30 ft. and an inside width of 8 ft.

The charge which rests on carriers is carried into the furnace on the four arms of a charging machine, the arms entering slots in the furnace hearth and being guided by rollers on the foreplate. After charging, the arms are lowered and withdrawn from under the charge leaving the charge resting on the bridge walls between slots in the hearth.

The furnaces are fired with town's gas through burners along each side, these being of the diffusion luminous flame type arranged so that the gas and air mix as they emerge from the nozzles. The waste gases are evacuated from the furnaces through ports in the slots in the hearths and passed through flues under the hearths in which are situated metallic recuperators for preheating the total air for combustion. The recuperators consist of aluminised solid-drawn steel tubes of the double tube type. The air passes through the inner tube and returns along the annulus, thence to a header box connected to the burner.

For control purposes the furnaces are divided into three zones, each being provided with temperature-control equipment, which operate from thermocouples and actuate linked gas and air proportioning port valves by Kent geared motors. The gas and air flow to each zone is measured by orifice plates in the cold air and gas mains, and the flow is indicated on differential gauges. By adjustment of the proportioning port valves in conjunction with the flow gauges, the gas/air ratio can be preset and maintained. In addition to the indicating controllers a Kent three-point recording pyrometer is provided to give a permanent record of the temperature

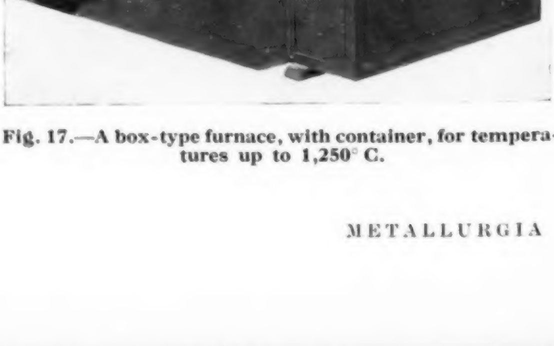


Fig. 17.—A box-type furnace, with container, for temperatures up to 1,250° C.

Fig. 18.—Three bogie-hearth furnaces by Brayshaw Furnaces & Tools, Ltd., for tempering steel plates.

in the three zones of each furnace. In addition furnace pressure control is provided by Reavell-Askania equipment operating the damper in the flue to the chimney. A draught gauge is included for setting purposes.

Particular attention has been paid in the design to ensure effective insulation and low heat storage capacity. Only the hearths and flue system under the hearths are of firebrick. The furnace crowns and side walls are of refractory insulating brick, coated with sillimanite for protection against flame abrasion. Diatomaceous-type insulating brick is used behind the refractory insulation lining of the side walls and crown and asbestos is introduced at the sides of the furnace between the insulating brick lining and the mild-steel furnace casing to reduce further the radiation losses.

Tests carried out on various charges have shown satisfactory temperature uniformity in the furnaces. A fuel consumption of 0·45–0·55 cu. ft. of gas per lb. of charge (dependent upon the type of charge) is regularly obtained. The waste gas analysis shows a consistently high CO_2 value corresponding to the desired setting.

A further example of furnace equipment for annealing copper tubes is shown in Fig. 13. Designed and built by Birlec, Ltd., this equipment is installed at Yorkshire Copper Works, Ltd.

For the continuous annealing of fine wire, a G.E.C. electric furnace, rated at 50 kW. has two muffles each designed to carry 51 stainless-steel tubes ½ in. outer diameter to provide for the annealing of 102 wires at one time. The overall length of 13 ft. 6 in. is divided up into two heated zones in addition to in and out going vestibules. Separate transformers and automatic temperature control are provided for each zone. The furnace can be used to give temperatures up to 750° C.

Hardening and Tempering

Several recent developments in the design of hardening and tempering furnaces have been introduced. An interesting one is the tilting hearth "Hydryzing" furnace of Electric Resistance Furnace Co., Ltd. This type of furnace enables the bright hardening of small parts, such as springs, stampings, etc., which are difficult to clean. Extremely light sections which are likely to cool below the critical, by contact with room air before quenching, can be quenched direct from the heating chamber of this furnace to ensure complete hardening results. The furnace, which is illustrated in Fig. 14, is so designed that the work is completely protected from the outside air, not only during heating but in quenching also. The method of quenching is referred to in some detail elsewhere in this issue.

Fig. 19.—Efco-Lindberg electric cyclone tempering equipment.

The hardening of small steel articles has always been difficult—conventional methods involving disadvantages such as scaling, dirty conditions, heavy metal wastage due to distortion and oxidation, and intermittent production. With these problems in mind Birlec, Ltd. have designed a new type of continuous furnace to overcome the difficulties of conventional methods. The essential feature of this new furnace, shown in Fig. 15, is a shaker hearth, which is particularly suited to the heat treatment of small articles like pins and needles, pen nibs, fish hooks, springs, screws, nuts, bolts and miscellaneous pressings and stampings. The shaker hearth is a nickel-chromium plate, agitated at predetermined intervals causing the charge to move through the heated furnace chamber at a controlled speed. The mechanism operating the shaker can be regulated and the time spent by the charge in the 20 kW. furnace can be varied from 2½ minutes to 2 hours. The atmosphere is controlled and the heated article pass direct into the collecting basket in the quench tank. This design is adaptable for both hardening and tempering, furnaces being installed in tandem or in parallel according to the shop layout.

The mesh-belt type of continuous furnaces is also much in use for hardening small steel articles. A typical furnace of this type, designed to give temperatures up to 900° C.—rated at 20 kW. and supplied by G.E.C., has a heated length of 4 ft., a belt-loading width of 8 in. and height 10 in. The variable-speed mesh-belt conveyor carries the parts through the heated zone after which they are discharged into an oil-quench tank beneath the furnace. An inclined "V" trough conveyor removes the quenched pieces and deposits them into a draining basket. A very different type is the batch furnace which continues to have wide usefulness. An interesting example being the double-doored oil-fired furnace for the heat treatment of springs shown in Fig. 16. The design is suitable for the use of either gas or oil as fuel. Two large installations of this type have been installed by Kasenit, Ltd. in works in London and

Wales. Operating up to a temperature of 950° C. this furnace gives admirable service.

A versatile furnace supplied by Electric Resistance Furnace Co., Ltd., for use up to temperatures of 1,250° C. is the box-type furnace with container shown in Fig. 17. The unit illustrated is rated at 12 kW. and is fitted with a gas-tight container having inside working dimensions 14 in. long × 12 in. wide × 7 in. high. This container is supplied complete with a clamped cover and inlet and outlet tubes for use with bottled hydrogen, cracked ammonia, or processed town's gas.

The furnace is in use for the annealing of magnetic alloys in small quantities and for copper brazing. Several containers can be used, if necessary, so that when the charge has been heated to temperature, one container can be withdrawn and allowed to cool with the protective atmosphere still passing. A second container is inserted in the furnace and heated up during this period. If necessary, the furnace can operate continuously with three containers. This is an inexpensive equipment and is much less costly than the normal bell-type bright annealing furnaces, conveyor type, or semi-continuous type. It is not necessary to install a special gas plant as the furnace will operate satisfactorily on bottled hydrogen.

An installation of three bogie hearth furnaces installed in a large Sheffield steel works for tempering steel plates is illustrated in Fig. 18. They are Brayshaw furnaces and are fired by town's gas. The furnaces on the right and left are fitted with burners arranged to fire direct into the furnace chamber whilst the centre furnace is of the forced convection type, and is heated by recirculated products. Recirculation is by means of a powerful fan mounted on the back of the furnace which recirculates a large volume of gases through the furnace chamber. For heating gas is burnt in a separate combustion chamber, and led into the main volume of recirculated gases. This particular furnace is suitable for a temperature range of 200°/700° C. and the design guarantees a temperature accuracy to within plus or minus 3° C.

Many products require tempering after being subjected to hardening heat treatments and, in keeping with all heat-treatment operations, economic production is much sought after. In this category is the Efco-Lindberg electric cyclone tempering furnace which provides high temperature regardless of the type of work loads. Extreme dense loads are tempered with the same accurate facility as obtained with loose or bulky loads. A typical example is shown in Fig. 19. Among other batch-type tempering furnace equipments widely used are the Homo-tempering units of The Integra Co., Ltd., of which there are two types: the production type, for tempering large loads; and the tool type, for tool room or laboratory work or for production departments where output is too small to justify a large production furnace.

Conclusion

Only a few typical examples of heat-treatment equipment installed recently have been given, many equally interesting have been unavoidably omitted, but those briefly noted indicate that furnace manufacturers are continuing progressive trends in design. While there has been no neglect in the further development of batch furnaces, during the past year developments in the heat-treatment furnace industry have largely centred around the demand for continuous heat-treatment processes. Such processes as hardening, annealing, normalising, brazing, etc., are now commonly carried out, with or without the use of controlled atmospheres, in furnaces of the roller hearth, rotary hearth and mesh-belt types even where very long heating cycles are required. The intermittent pusher-type furnace, where the charge is progressed through the furnace in stages, is also being used for some processes in preference to the batch furnace.

Wire Drawing Achievement

A NOTABLE achievement in the drawing of fine tungsten wire was recently made in the wire-drawing section of the Osram Lamp Works of the General Electric Co., Ltd., when a length of 33 miles of 0·05 mm. dia. wire was drawn without a break. The wire started as an ingot of sintered tungsten 10 in. long and was passed through 57 tungsten carbide and diamond dies before being reduced to its final diameter. The drawing time was 100 hours and during this time the metal traversed a distance of 250 miles. At its final thickness, about $\frac{1}{8}$th of that of a human hair, it will be used in the manufacture of electric lamp filaments.

Marform Process

A NEW efficient and economic process of precision metal forming known as the "Marform Process" has been developed by The Glenn L. Martin Co., U.S.A. By arrangement with that Company, The Loewy Engineering Co., Ltd., Manfield House, 376, Strand, London, W.C.2, will undertake the introduction of the Marform Process in the United Kingdom, the British Commonwealth, Europe and other export territories. Complete presses as well as equipment for incorporation into existing presses to carry out the Marform Process will be supplied by Loewy Engineering who intend to build the equipment in their works at Light Machines, Ltd., Yeovil. Technical information and assistance is available for potential and actual users of the process.

General Purpose Furnace

THE hardening of single components of slender section and batches of components which can be suspended on jigs, carburising of circular components such as crown wheels and similar parts, normalising and annealing forgings and castings and, with the addition of suitable retorts, used for the reduction of oxides in reducing atmospheres—such are the many uses for which a new vertical general purpose furnace may be employed. Manufactured by Wild-Barfield Electric Furnaces, Ltd., Elecfurn Works, Watford, Herts., the standard size is made in two models, the VW 1 and VWP 1, the former being a straightforward furnace and the latter, identical in every respect, but with the added advantage of the Paragen atmosphere control unit, which is strongly recommended where the treatment of steels are to be carried out with commercial freedom from decarburisation. The heating elements are so arranged about the chamber to operate at a low temperature, thus assuring longer life for a set furnace temperature and allowing a chamber temperature of 1,050° C. (1,922° F.) to be reached with safety. Adequate devices are incorporated to safeguard both operator and furnace.

A new leaflet dealing with these furnaces is in course of preparation and copies will be reserved for any readers who care to apply to the Wild-Barfield firm for one.

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A Free Cone Bend Test for Aluminium Alloy Sheets and Coils

By W. Thompson, A.F.R.Ae.S.
A.I.D., Harefield House, Harefield, Middlesex

Specifications for the thinner gauge light alloy sheets usually call for a bend test in place of an elongation determination as evidence of adequate ductility. The requirements are usually well within the capacity of the material and in this article the author describes a single test which is capable of determining more accurately the limiting radius of bend which the material is able to withstand.

THE specifications for aluminium alloys seldom call for an evaluation of the ductility of sheets and coils which are not thicker than 0·104 in. (12 S.W.G.). For these thinner gauge materials, both the British Standard and the D.T.D. series of specifications substitute single bend tests for the determination of percentage elongation values. It is usually laid down that suitably prepared test pieces must withstand, without cracking being bent through 180° round a former having a radius which is related to the nominal thickness of the sheet or coil by the formula $R = at$, where R is the radius, a is a specified coefficient, and t is the nominal thickness.

The specified radius of bend, however, is usually well within the bending capacity of the sheet or coil, if the material is satisfactory ; thus, while the test may detect relatively severe embrittlement, it does not furnish a discriminating acceptance standard in respect of ductility.

In order to obtain a quantitative indication of bending capacity, it is necessary to determine the smallest radius to which a material can be bent without cracking. An approximation to this value may be obtained with the conventional types of apparatus by bending successive test pieces to progressively smaller radii but, if small differences in ductility are to be detected, the differences in the radii of successive formers or bending pins must be correspondingly small. In consequence, the evaluation of a single sheet or coil may involve the preparation and testing of a considerable number of test pieces.

A further disadvantage associated with this method of evaluation lies in the fact that the limiting radius of bend values obtained may depend to a considerable extent on the type of apparatus employed. In practice it is often difficult to maintain intimate contact between former and test piece throughout the test, with the result that failure may occur at a local decrease in the radius of curvature. On the other hand, if excessive pressure is applied to ensure intimate contact, the resulting frictional effects may tend to mask the physical significance of the test values obtained. In this connection British Standard Specification 3.A.4 recommends that when the capacity of a material to satisfy the bend test requirements is in doubt, testing shall be effected by pressing the test piece into a block of soft lead by means of a former of the requisite radius.

It is possible to achieve reasonable reproducibility of results with this method but, when it is applied to determining limiting radius of bend values, it is apt to prove time consuming, and of course a considerable number of formers are required. Accordingly it was decided that the development should be undertaken of apparatus for determining limiting radius of bend values in a single operation. A secondary objective was the elimination of formers or bending pins.

Theoretical Considerations

Consideration was first given to a method of bending recommended by the A.S.T.M.,[1] in which a suitably prepared test piece is given an initial bend of between 5° and 30°, placed endwise in a vise or press, and a compressive force applied. The vise or press is closed until failure of the test piece occurs, and an evaluation of the ductility is made by measuring the outside fibre elongation.

While this procedure is clearly unsuitable for the thinner gauges of material, it was thought that the method of free bending offered a promising approach to the problem.

In order to study the behaviour of a standard test piece—i.e., 0·5 in. wide × 2 in. long × thickness, under the action of an end load, a number of assumptions were made. In practice the load will never be applied perfectly axially, so it was assumed that its line of action was parallel to the longitudinal axis of the test piece, and intersected an axis of symmetry of the cross section at a fixed distance from the centroid. In this manner it was possible to construct a Howard Polar Diagram[2] for a 2 in. long test piece of known physical characteristics. A further diagram was then constructed for a test piece of the same material and cross section but $2\frac{1}{2}$ in. long, and with the end load reduced to give

[1] American Society for Testing Materials Designation E16–39.
[2] Stresses in Airplane Structures—Howard.

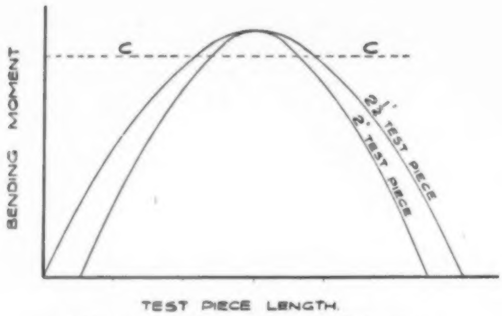


Fig. 1.—Bending moment diagrams.

the same maximum bending moment as that imposed on the 2 in. long test piece. Fig. 1 illustrates the bending moment diagrams which were obtained when the polar co-ordinates were replaced by Cartesian co-ordinates.

If it is now assumed that the test piece commences to bend when the bending moment is at, or approaching, a critical value—e.g., at a bending moment of C in Fig. 1—it will be observed that the portion of the $2\frac{1}{2}$ in. long test piece in the region of critical stress is longer than that of the 2 in. long test piece. It was therefore inferred that, when yielding occurs, it will take place on a greater length of the $2\frac{1}{2}$ in. long test piece than the 2 in. long test piece, and that the radius of bend will be correspondingly larger.

It was also considered likely that if a test piece were to be work hardened, or heat treated in a manner which would increase the resistance to bending, the bending moment necessary to induce the critical fibre stress would also have to be increased. The curve of the bending moment diagram would therefore be sharper than the curve of a similar test piece with a lower resistance to bending and, since a smaller portion would be in the region of critical stress, the radius of bend would be correspondingly smaller.

The remaining factor which will influence the radius of bend will be the amount by which the test piece is allowed to buckle. The bending will become localised at the centre as the flexural rigidity approaches zero and, as the ends of the test pieces approach one another, the radius of bend will decrease.

In order to check these assumptions, a number of preliminary experiments were carried out. Twelve 2 in. long × 0·5 in. wide × 16 S.W.G. test pieces in material to specification B.S. 5.L.3 were prepared with chamfered ends so that they would be free to take up any angular position. They were then mounted endwise between the compression plates of a tensile machine, and compressed by means of steadily applied pressure. It was observed that, immediately after buckling occurred, bending was confined to the central region of the test piece, and that the curvature on either side was negligible. The radii of bend were measured by means of radius gauges, and in each instance, the radius of bend decreased progressively as the angle of bend was increased.

Two strips 0·5 in. wide were then cut from the same sheet of 16 S.W.G. material, and one strip was stressed in tension until the elongation on a gauge length of 2 in. was 0·5%. Bend test pieces varying in length from $1\frac{1}{4}$ to $2\frac{1}{2}$ in., in steps of $\frac{1}{8}$ in., were prepared from each of the two strips, and were loaded in compression until the angles of bend were 120° When the radii of bend were measured it was found that they varied in proportion to the original lengths of the test pieces. Also, in each instance the radius of bend of a test piece from the strained strip was smaller than that of a test piece of the same length from the unstrained strip.

From the results of these experiments it was concluded that, if a test piece were prepared in the form of a trapezium having two sides evenly tapered, and pressure were applied at the tapered edges until buckling occurred, the radius of bend would increase progressively from one end of the test piece to the other. It was also considered probable that, if the radius of bend at the narrow end were too small for the material to withstand, a crack would develop and extend along the longitudinal axis of the test piece to the point where the radius was sufficiently large to allow of satisfactory bending. The radius at that point would be the limiting radius of free bending.

Description of Apparatus and Test Procedure

The apparatus which was eventually designed, consists of an upper and lower steel platen; attached to the lower platen there are two rectangular guide members on which the upper platen is free to slide vertically. The platens are tapered and so disposed that the perpendicular distance between their inner faces increases progressively from one end to the other. There is a small semi-circular groove running longitudinally through the centre of each of the inner faces, and four adjustable-screw stops are provided to arrest the downward movement of the upper platen at any desired position. Pressure is applied to the top platen through a shank attached to its upper face, and the distance through which it has moved may be measured at any stage of the test by reference to a scale attached to one of the guide members.

If the nominal thickness of the material to be tested is 16 S.W.G. or less, the test piece is prepared to the shape and dimensions of Type A, Fig. 2; for thicker materials the Type B test piece which is $\frac{1}{8}$ in. wider may be used. In practice it has been found convenient to construct a template of each type. The preparation of the test pieces then consists of marking out, guillotining to shape, and chamfering the longer edges with a file.

The test piece is mounted between the platens with its converging edges resting in the semi-circular grooves. Pressure is then steadily applied to the upper platen and, after the buckling load has been reached, the test piece commences to bend symmetrically about its longitudinal axis. The bending operation is continued until a crack is generated at the narrow end of the test piece—i.e., at the point of greatest curvature.

If the test is being carried out for ductility comparison purposes, the scale reading is noted at which a crack

TABLE I.—DETERMINATION OF LIMITING RADII OF BEND

Specification	Thickness of Test Piece (Inch)	Limiting Radius of Bend (in.)		
		Free Cone Apparatus	Lead Block Method	
			Passed	Failed
D.T.D. 603 ..	0·029	0·035	0·036	0·033
D.T.D. 610 B..	0·038	0·040	0·042	0·037
D.T.D. 390 ..	0·048	0·045	0·048	0·042
D.T.D. 610 B..	0·050	0·050	0·048	0·042
CGA.	0·052	0·060	0·064	0·054
BS. 5L3	0·064	0·090	0·096	0·084
D.T.D. 390 ..	0·078	0·070	0·072	0·064
D.T.D. 603 B..	0·079	0·070	0·072	0·064

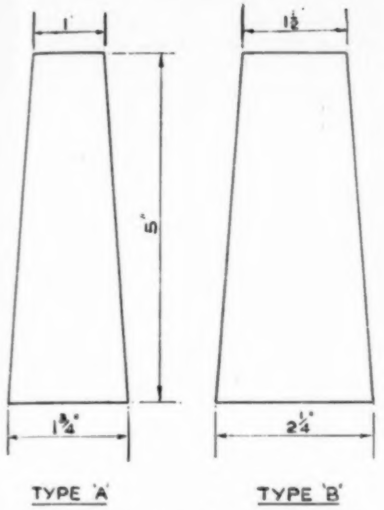


Fig. 2.—Free cone bend test pieces.

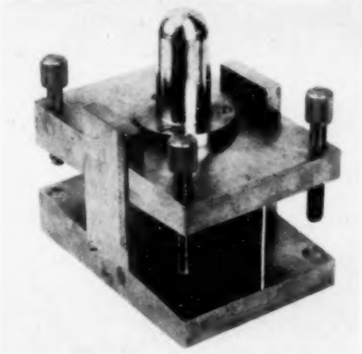


Fig. 3.—Bending jig with test piece ; commencement of test.

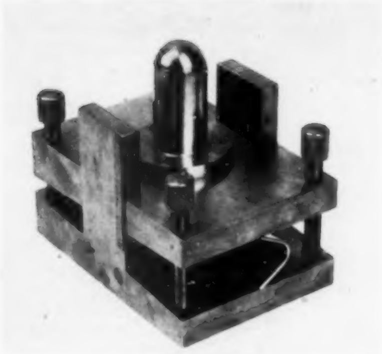


Fig. 4.—Bending jig with test piece ; conclusion of test.

occurs. The screw stops are then set to ensure that subsequent test pieces are bent through the same angle. Figs. 3 and 4 show respectively the apparatus at the commencement and at the conclusion of a test. Fig. 5 illustrates a typical test piece after bending : it will be observed that the deformed region is in the form of a section of a hollow cone with the radius increasing progressively from one end to the other. The radius of bend at the end of the crack is the limiting radius of free bend of the material under test.

If there is any doubt as to where the crack actually terminates, a further determination may be made, by replacing the test piece between the platens and re-applying the load until the crack extends a little further.

Experimental

Curvature Check.—To confirm the circularity of the curvature at any point along the deformed regions of the test pieces, a 14 S.W.G. test piece and a 20 S.W.G. test piece were tested and the curvature measured. Enlarged reproductions of the curvature at five evenly-spaced positions along each test piece were compared with the nearest co-incident true arcs, and it was found that, at a magnification of $\times$ 20, the actual curvature of the bends showed no appreciable deviation from the circular.

Determination of the Limiting Radii of Bend.—The first series of experiments was carried out to compare the limiting radius of bend values, obtained with the free cone bend apparatus, with those obtained by the soft lead block and former method of bending. Ten free cone and ten standard 2 in. long $\times$ $\frac{1}{2}$ in. wide bend test pieces were prepared from each of eight different aluminium alloy sheets, care being taken to ensure that the angle of bending with respect to the direction of final rolling of the sheets would be the same for each set of test pieces. The limiting radii of bend were determined on the free cone bend test pieces, using radius gauges to measure the radii, and it was found that all the results from the test pieces from the same sheets were sensibly the same.

The limiting radii of bend of the standard bend test pieces were then determined using a soft lead block and steel formers. The difference between the radii of contiguous formers was sufficiently small to allow the limiting radius of bend to be determined within 0·008 in. and in these experiments, the smallest radius over which a test piece would bend satisfactorily was recorded, together with the radius of the next smaller former in the series.

It will be observed from Table I, that the limiting radius values obtained by the two different methods of bending were in very close agreement.

The Detection of Small Differences in Bending Capacity.—The second series of experiments was carried out to ascertain whether the apparatus could be employed for detecting small differences in bending capacity. Five strips of material to specification B.S. 5.L.3, 24 in. long $\times$ $2\frac{1}{2}$ in. wide $\times$ 16 S.W.G., were solution treated and aged in accordance with specification requirements. Four of the strips were then loaded in tension until they had undergone a permanent extension (as measured on a 5 in. gauge length) of 1, 2, 3 and 4%, respectively.

Four free cone and twelve standard bend test pieces were prepared from each of the strained strips, and also from the unstrained strip. The standard test pieces were tested in the same manner as before, and it was found that the differences in the limiting radius of bend values were too small to employ for comparison purposes. The preliminary single bend test experiments, however, had shown that when bending was effected by the application of an end load, the radius was related to the original length of the test piece, and the angle through which it had been bent. In addition it appeared to be related to the condition of the material since, in each instance, the radius of bend of a test piece from the strained strip had been smaller than that of test pieces from the unstrained strip. Hence it was expected that, if the angle of bend were kept constant, the different amounts by which the free cone bend test pieces had

Fig. 5.—Typical test piece after bending.

been strained would result in the limiting radii occurring at different positions along their longitudinal axes. Accordingly the screw stops of the free cone bend test apparatus were adjusted to ensure that the distance between the inner faces of the platens at the conclusion of the test would be the same for all the test pieces.

All the free cone bend test pieces were compressed until the screw stops were firmly in contact with the lower platen and, when they were examined, it was found that the lengths of the cracks increased progressively in roughly 1 in. steps from 0·5 in. on the unstrained test pieces to 4·5 in. on the test pieces which had been elongated by 4%. A set of five typical test pieces, one from each group is shown in Fig. 6.

This experiment was repeated with test pieces prepared from 18 S.W.G. material to D.T.D. 610B and, as will be observed from Tables II and III, the length of the cracked portion of each of the test pieces was proportional to the amount by which it had been prestrained in tension.

The Effect of Variations in Solution Treatment Temperature on Bending Capacity.—One hundred standard and 24 free cone bend test pieces were prepared from a sheet of 16 S.W.G. material to Specification B.S. 5.L.3, and solution treated at temperatures ranging from 495° to 530° C. After ageing for five days they were tested, and, as in the previous experiments, it was found that there was no appreciable difference between limiting radius of bend values. The lengths of the cracked portions of the test pieces varied considerably and, as will be seen from Table IV, their bending capacity appeared to reach a maximum after solution treatment at 515° C.

When this experiment was repeated using 16 S.W.G. material to Specification D.T.D. 610A, however, there

TABLE II.—DETECTION OF SMALL DIFFERENCES IN DUCTILITY
Material: 16 S.W.G. Aluminium Alloy (BS. 5L3)

Group Number	Tensile Strain Inch per Inch	Free Cone Bend Test Apparatus: Limiting Radius of Bend (Inch)	Free Cone Bend Test Apparatus: Length of Cracked Portion of Test Pieces (Inches)	Lead Block Method: Limiting Radius of Bend (Inch): Passed	Lead Block Method: Limiting Radius of Bend (Inch): Failed
1	Nil	0·065	0·50	0·072	0·064
		0·065	0·50	0·072	0·064
		0·065	0·56	0·072	0·064
		0·065	0·60	0·072	0·064
2	0·010	0·085	1·44	0·096	0·084
		0·085	1·50	0·096	0·084
		0·085	1·40	0·096	0·084
		0·085	1·45	0·096	0·084
3	0·020	>0·085	2·50	0·096	0·084
		>0·085	2·45	0·096	0·084
		>0·085	2·40	0·096	0·084
		>0·085	2·46	0·096	0·084
4	0·030	0·095	3·50	0·096	0·084
		0·095	3·56	0·096	0·080
		0·095	3·50	0·084	0·080
		0·095	3·52	0·084	0·080
5	0·040	0·105	4·44	0·108	0·104
		0·105	4·38	0·108	0·104
		0·105	4·25	0·108	0·104
		0·105	4·4	0·108	0·104

TABLE III.—DETECTION OF SMALL DIFFERENCES IN DUCTILITY
Material: 18 S.W.G. Aluminium-coated Aluminium Alloy (D.T.D. 610B)

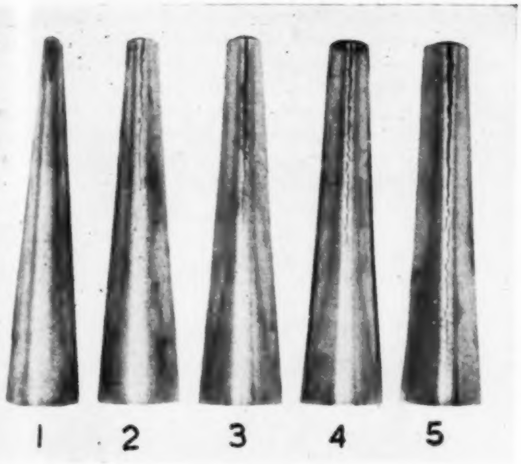
Group Number	Tensile Strain Inch per Inch	Free Cone Bend Test Apparatus: Limiting Radius of Bend (Inch)	Free Cone Bend Test Apparatus: Length of Cracked Portion of Test Piece (Inches)	Lead Block Method: Limiting Radius of Bend (Inch): Passed	Lead Block Method: Limiting Radius of Bend (Inch): Failed
1	Nil	0·040	0·25	0·042	0·037
		0·040	0·19	0·042	0·037
		0·040	0·25	0·042	0·037
		0·040	0·20	0·042	0·037
2	0·010	0·050	1·50	0·054	0·048
		0·050	1·40	0·054	0·048
		0·050	1·40	0·054	0·048
		0·050	1·39	0·054	0·048
3	0·020	0·060	2·62	0·064	0·054
		0·060	2·62	0·064	0·054
		0·060	2·60	0·064	0·054
		0·060	2·62	0·064	0·054
4	0·030	0·075	3·62	0·084	0·080
		0·075	3·75	0·084	0·080
		0·075	3·70	0·084	0·080
		0·075	3·75	0·084	0·080

TABLE IV.—EFFECT OF VARIATIONS IN SOLUTION TREATMENT TEMPERATURE
Material: 16 S.W.G. Aluminium Alloy (B.S. 5L3)

Sample Number	Solution Treatment Temp. °C.	Free Cone Bend Test Apparatus: Limiting Radius of Bend (Inch)	Free Cone Bend Test Apparatus: Length of Cracked Portion of Test Piece (Inches)	Lead Block Method: Limiting Radius of Bend (Inch): Passed	Lead Block Method: Limiting Radius of Bend (Inch): Failed
1	495	0·085	1·75	0·084	0·080
2	,,	0·085	1·75	0·084	0·080
3	,,	0·085	1·87	0·084	0·080
4	,,	0·085	1·90	0·084	0·080
5	505	0·080	1·5	0·080	0·072
6	,,	0·085	1·37	0·080	0·072
7	,,	0·080	1·37	0·080	0·072
8	,,	0·080	1·44	0·080	0·072
9	515	0·080	1·3	0·080	0·072
10	,,	0·080	1·37	0·080	0·072
11	,,	0·080	1·37	0·080	0·072
12	,,	0·080	1·25	0·080	0·072
13	520	0·085	1·62	0·084	0·080
14	,,	0·085	1·5	0·084	0·080
15	,,	0·085	1·5	0·084	0·080
16	,,	0·085	1·48	0·084	0·080
17	525	0·095	1·87	0·096	0·084
18	,,	0·095	1·75	0·096	0·084
19	,,	0·095	1·62	0·096	0·084
20	,,	0·095	1·62	0·096	0·084
21	530	0·095	2·75	0·096	0·084
22	,,	0·100	3·87	0·096	0·084
23	,,	0·095	3·25	0·096	0·084
24	,,	0·125	3·9	0·096	0·084

TABLE V.—EFFECT OF VARIATIONS IN SOLUTION TREATMENT TEMPERATURE
Material: 16 S.W.G. Aluminium-coated Aluminium Alloy D.T.D. 610A

Sample Number	Solution Treatment Temp. °C.	Free Cone Bend Test Apparatus: Limiting Radius of Bend (Inch)	Free Cone Bend Test Apparatus: Length of Cracked Portion of Test Piece (Inches)	Lead Block Method: Limiting Radius of Bend (Inch): Passed	Lead Block Method: Limiting Radius of Bend (Inch): Failed
1	505	0·065	0·50	0·064	0·058
2	,,	,,	0·55	,,	,,
3	,,	,,	0·50	,,	,,
4	,,	,,	0·50	,,	,,
5	510	0·065	0·75	0·064	0·058
6	,,	,,	0·75	,,	,,
7	,,	,,	0·80	,,	,,
8	,,	,,	0·70	,,	,,
9	515	0·065	0·75	0·064	0·058
10	,,	,,	0·75	,,	,,
11	,,	,,	0·85	,,	,,
12	,,	,,	0·80	,,	,,
13	520	0·070	0·85	0·064	0·058
14	,,	,,	0·90	,,	,,
15	,,	,,	0·90	,,	,,
16	,,	,,	0·95	,,	,,
17	525	0·095	1·75	0·084	0·072
18	,,	,,	1·85	,,	,,
19	,,	,,	1·90	,,	,,
20	,,	,,	2·00	,,	,,
21	530	0·120	2·75	0,108	0·096
22	,,	,,	2·50	,,	,,
23	,,	,,	2·62	,,	,,
24	,,	,,	2·62	,,	,,



Sample 1. Material as received.
Sample 2. Material prestrained by 1%.
Sample 3. Material prestrained by 2%.
Sample 4. Material prestrained by 3%.
Sample 5. Material prestrained by 4%.

Fig. 6.—Test pieces after bending, showing the effect of pre-straining.

was a marked increase in both the lengths of the cracked portions of the test pieces, and the limiting radius of bend values, as the solution treatment temperatures were increased. It was also found that, where the solution treatment temperatures had been at, or in excess of, 520° C., the limiting radii obtained with the free cone apparatus were greater than those obtained using the lead block and steel former method of bending. It was thought that solution treatment of this material at a temperature above the specified maximum induces a moderate degree of notch sensitivity. The results obtained are shown in Table V.

Conclusions

The preliminary experiments, and the data obtained, suggest that the apparatus may have a useful application in both acceptance tests and in those investigatory tests where it is desired to detect small differences in bending capacity. At the outset it was considered likely that the notch effect of the cracked portion of the test piece might lead to spurious results being obtained, but with the possible exception of D.T.D. 610A sheet which had been solution treated at a temperature in excess of the specified maximum, the limiting radius of bend values were sensibly the same as those which were obtained using the lead block and former method of testing.

The experiments were confined to aluminium alloys, but there is no reason to suppose that the apparatus would not prove useful for other types of metallic and non-metallic sheet materials.

Acknowledgment

Acknowledgment is made to the Ministry of Supply for permission to publish this paper.

Miscellaneous Microchemical Devices (XXV)

A Modification of the Lidstone-Wilson Micro Hydrogen Sulphide Generator

By J. T. Stock, P. Heath and W. Marshment

In our hands, the micro hydrogen sulphide generator described by Lidstone, Wilson and Wilson[1] has proved highly successful. The apparatus is of simple construction, is compact and hence easily portable, and delivers gas at a satisfactorily high pressure. Having constructed and used several models, a few points have suggested themselves.

As a precautionary measure, and to ascertain the rate of delivery before inserting the delivery tube into the sample, we make a practice of passing the issuing gas through a bubbler containing water. If the bubbler is sufficiently light, it may of course be sealed to the side-arm scrubber-bulb which is packed with glass wool. However, the chances of breaking off the entire side-arm are then increased. Alternatively, the bubbler may be mounted on the base of the generator, connection to the generator outlet being made by means of rubber tubing. A third arrangement, which we have found to be very satisfactory, is to use an internal scrubber, so that a small bubbler may be sealed directly to the gas outlet.

This modification is shown in Fig. 1. The stem *A* of the acid reservoir funnel passes down the straight, 10-mm. bore, portion of tee-piece *B*, the lower end of which is constricted until only about 1 mm. greater in diameter than the stem of the funnel. The lower part of the annulus thus formed is lightly packed with glass wool, which may be easily withdrawn and replaced when necessary. Bubbler *C* is sealed on as shown and is given additional support by the shaped pad of cork *D* which is slipped between the adjacent portions of the bubbler and the generator. A wide rubber band *E* provides the securing force.

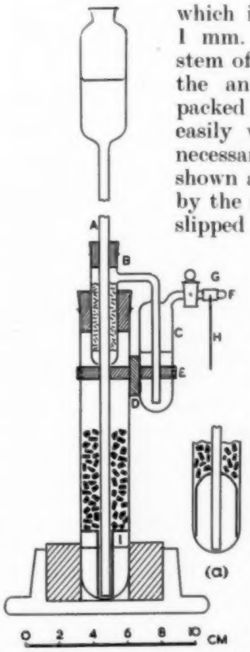


Fig. 1.—Generator with internal scrubber.

As an alternative to the usual tapered delivery tubes, the "plug-in" method, using fine, uniform tubes, has been adopted.[2] The side arm *F*, projecting beyond the stopcock is sealed off and, about 10 mm. from the end, a hole some 3 mm. in diameter and inclined downwards at about 45° is blown. A short length of thin rubber tubing *G* is then slipped on and forms a diaphragm over the hole. Having punctured the centre of the diaphragm with the red-hot point of a sewing needle, a delivery tube *H* of some 0·3 mm. outside diameter may be thrust into the hole and will be securely gripped. Such delivery

1 Lidstone, A. G., Wilson, C. L., and Wilson, D. W., *Metallurgia*, 1947, **35**, 171.

2 Stock, J. T., and Heath, P., *ibid*, 1950, **41**, 171.

tubes are readily pulled from scrap tubing and are thrown away after use.

It is worth noting that the height of the circular table *l*, upon which rests the charge of iron sulphide, should not be too small. If this table is made too low, the film of acid left on the charge when the acid recedes is sufficient to yield enough gas to force the acid down to the level of the bottom of the funnel-stem, so that gas bubbles rise up the stem and escape into the atmosph re.

Unless expertly made, the flange of the circular ta ble is inclined to be uneven in thickness and hence rat ner weak. Chipping at the edges then occurs dur ng charging. From the point of view of strength and c se of construction, we have found the modified table sh wn at (*a*) to be very satisfactory. Its construction f om the lower portion of a boiling tube is obvious.

The Physical Society Exhibition*

This exhibition, the fifth of its kind to be held since the war, showed clearly the rapid advance made by the scientific instrument industry. A stage has now been reached where British firms can compete, in almost every field, with those of other countries. Reference is made to some of the items of particular interest to workers in the metallurgical field.

THE Physical Society's 34th Annual Exhibition of Instruments and Apparatus has once again demonstrated the widespread interest in this aspect of scientific development. The object of the Society (as stated in its Articles of Association) is to promote the growth and diffusion of a knowledge of physics, and the Annual Exhibition, with its accompanying Discourses, is one of the activities directed to this end. Whilst the majority of the exhibits were displayed by the scientific instrument manufacturing industry, and represented commercially available equipment, there were numerous examples of physical research, particularly from Government departments and trade associations, illustrating the increasing application of physical principles to the solution of a diverse range of problems.

The interest aroused was evident from the large attendances at each session of the Exhibition, and for the benefit of those readers who were unable to make a personal visit we are presenting, in the following pages, brief information on those items which are likely to be of interest to workers in the metallurgical sphere. It is appreciated that many of the instruments are of general application in the scientific field but, in view of space limitations, we shall content ourselves with dealing only with those items of direct interest to the metallurgist.

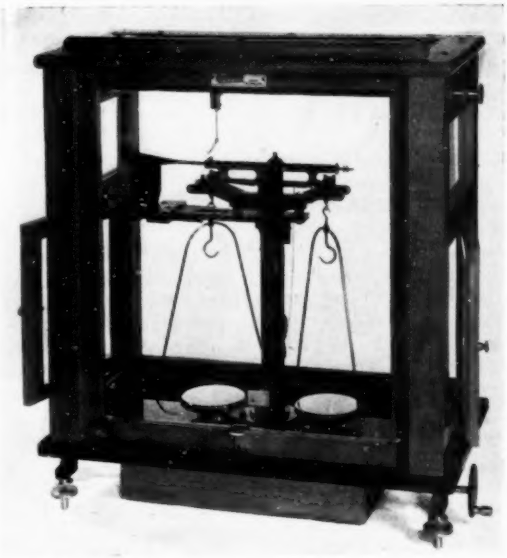
Balances

The four balances shown by L. OERTLING, LTD., included an aperiodic prismatic-reflecting weight-loading balance, Model 62FM, with a capacity of 200 gm. per pan and a sensitivity of 0·2 mg. per graticule division of 1·5 mm. Bearings of extreme accuracy and durability are provided by matching agate knives with corundum planes and a calibrated weight-loading mechanism eliminates the need for weights below 1 gm. Also shown was the Model 101 gram-chain balance, which has recently replaced the Model 48GC and is fitted with magnetic damping; without opening the case, however, it may be rendered free-swinging. Two prismatic-reflecting micro-chemical balances were exhibited, Model 63PA/PB and Model 141. The respective capacities are 20 gm. and 30 gm. per pan, and the sensitivities 0·001 mg. and 0·01 mg. per division. Model 141 is fitted with automatic weight loading up to 0·09 gm. and has a graticule range of 0·01 gm.; air-damping ensures rapid operation. Heat from the external projection lamp is prevented from penetrating the balance case by a window of Calorex glass in both models, whilst Model 63PA/PB has a double case to increase stability under changes of ambient temperature. Standard and micro-chemical weights were displayed in a nickel-chromium alloy which, it is claimed, approaches most nearly to the ideal of a hard, non-magnetic metal resistant to corrosion by both oxidising and sulphur fumes. In addition to meeting N.P.L. tolerances for individual weights, inter-calibration prevents cumulative errors when using a number of weights.

The STANTON INSTRUMENTS, LTD. display included a prismatic-reflecting aperiodic balance, Model B.A.5 which has a loading attachment permitting loads up to 200 gm. to be placed by external means and read accurately to ± 0·0001 gm. The weights are of 25/20 stainless steel to N.P.L. tolerances and special care is taken to avoid cumulative errors. Synthetic sapphire (corundum) bearing planes are fitted throughout. The Model M.C.1/A also shown is an aperiodic micro-balance of 20 gm. capacity and a sensitivity of 0·01 mg. with which it is possible to read accurately to 3 mg. Nickel-chromium ring riders up to 0·1 gm. can be lowered by external means and a glass shelf isolates the beam from the rest of the balance case. A "double-action" beam arrestment mechanism results in an exceptionally smooth "set-off." The need for high accuracy at heavy loads is fulfilled by the Stanton 1 kg. precision balance with which an accuracy of 0·1 mg. is attainable, whilst at the other extreme is a balance with a sensitivity of 1 microgram, and a capacity of 5 gm., designed for adjustment of weights to high standards of accuracy. The Stanton sets of weights displayed were of stainless steel and the series consisted of 50, 30, 20, 10, 5, 3, 2, 1 instead of the usual 50, 20, 20, 10, 5, 2, 2, 1. This obviates the need for differentiation between similar weights and many results can be obtained using fewer weights. Of general interest was a special 5·9 kg. balance, with a sensitivity of 50 mg. fitted with a loading attachment operated by a servo mechanism, thus enabling remote control to be achieved.

Further balances were exhibited by W. & J. GEORGE & BECKER, LTD. The Nivoc analytical balance 537-5 is fitted with magnetic damping which reduces the oscillating time from 10 minutes to 12 seconds for a displacement of 5 divisions. The stray field is negligible and does not affect the apparent weights of ferro-magnetic objects. The Nivoc aperiodic-reflecting balance A6500 has a capacity of 200 gm. and a sensitivity of

* Held at the Imperial College, London, from Friday, 31st March to Wednesday, 5th April, 1950.



Oertling Model 101 gram-chain balance.

0·1 mg. Ring weights of 600 mg. and 300 mg. enable readings up to 1·2 gm. to be made without opening the case. For semi-micro work, an aperiodic balance ND126 with a 50 gm. capacity and a sensitivity of 0·01 mg. was shown. Air damping is provided and the external projection lamp condenser is fitted with a heat filter. A four position external weight change mechanism enables 0, 30, 60 or 90 mg. to be added. The Nivoc anti-vibration table ND122 has been developed to enable balances and instruments to be used in positions which would otherwise be impracticable.

The Microid analytical balance, exhibited by GRIFFIN & TATLOCK, LTD., is of conventional design with a capacity of 200 gm. and a sensitivity of 0·1 mg. Standard weights are used and the beam is scaled for the use of a 5 mg. rider.

A single pan balance of radically new design was shown by J. W. TOWERS & Co., LTD. The capacity is 200 gm. and sensitivity 0·1 mg. The load on the beam is always brought to 200 gm. by removing weights equal to that of the sample. From 0·1–199·9 gm. the weights are operated by four control knobs and the total sample weight read off a direct reading indicator. The weight less than 0·1 gm. can be read to 0·1 mg. on the illuminated scale. Corundum optical planes are fitted and air-damping ensures rapid operation. The Model 98 air-damped balance has a 200 gm. capacity and a sensitivity of 0·1 mg. The pointer carries a photographic graticule calibrated 0–100 mg. and four ring weights totalling 900 mg. are externally operated so that weights below 1 gm. are unnecessary. Corundum planes are also fitted to this model.

Analytical Equipment

The last few years have seen a considerable increase in the use of the photo-electric absorptiometer for colorimetric chemical analysis. BAIRD & TATLOCK (LONDON), LTD. had on show their self-balancing instrument designed and produced in collaboration with I.C.I. for the detection and recording of small changes in the colour of a liquor being used in a chemical process. For this purpose a small sample is by-passed through a "continuous flow" type of absorption cell. With suitable colour filters the instrument may be calibrated to determine the composition of any liquid whose absorption can be related to some form of chemical analysis or turbidity, ordinary "static" cells being used for individual analyses and readings taken on the milliameter on the front panel.

Other absorptiometers exhibited included the EVANS ELECTROSELENIUM "Eel" Model which will take standard optical cells up to 10 cm. in length. Measurements may be made with narrow band spectrum filters, readings being taken on a robust 4-in. meter. The instrument shown by THE EDISON SWAN ELECTRIC CO., LTD. is a self-contained mains-operated instrument of high sensitivity and stability. Readings are provided on a robust milliameter.

Vitreosil absorption cells for use in spectrophotometry were displayed by THE THERMAL SYNDICATE, LTD., together with a range of filtering and ignition crucibles, used extensively in chemical laboratories as they allow filtering and ignition to be carried out in the same crucible.

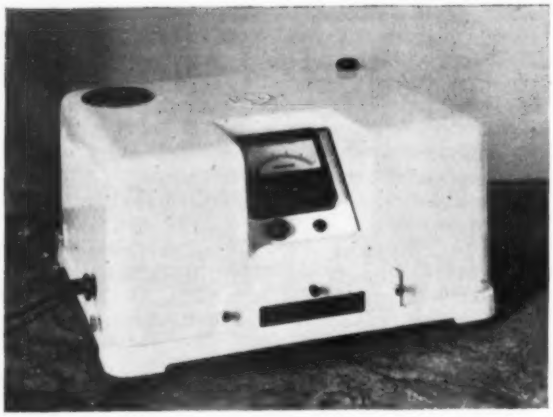
On the spectrographic side, the Hilger Division of HILGER AND WATTS, LTD. had on show a new compact 3-metre grating spectrograph in which compactness is secured by a "folded" optical path using a surface reflecting mirror. Interlinked adjustments, actuated by a push-button controlled motor, enable any range of wavelengths to be selected. Made in two designs, one has hand-operated plate-holder racking, whilst the other is operated from a centrally situated control desk. Plateholder movement can be continuous at a pre-selected speed, or intermittent with pre-selected distances between spectra. The plateholder movement switches are so arranged that, once the appropriate conditions have been pre-selected, a push-button sets in train a complete sequence of pre-spark. exposure and plate racking, each phase being indicated by coloured lights on the control board. A ruled diffraction grating of 14,400 lines per inch is used.

In some spectrochemical laboratories carrying out a large volume of qualitative analysis, the examination and comparison of large numbers of spectrum photographs poses difficult problems owing to the fatigue suffered by operators using eyepiece spectrum comparators for several hours at a stretch. As a means of reducing this fatigue, Hilger and Watts have developed a projection spectrum comparator in which both eyes are used.

When accurate pH measurements are being made, attention must be paid to the temperature of the solution under test. GRIFFIN & TATLOCK, LTD. have developed equipment for this purpose, comprising a glass electrode-saturated calomel electrode assembly immersed in a water thermostat so arranged that temperatures below room temperature may also be used. Control to 0·1° C. is readily obtained. Connection to the unknown solution is made through a ground-glass joint wet with potassium chloride. The glass electrode may be replaced by other electrode systems and pH measurements with a reproducibility of 0·02 or, with care, 0·01 pH units, can be obtained.

X-ray Crystallography

For many years there has been a demand for more intense beams of X-radiation for the study of materials which are changing, and to reduce the long exposure



Baird & Tatlock self-balancing photoelectric absorptiometer for chemical analysis.

times for the examination of such specimens. To achieve such beams it is necessary to rotate or oscillate the target and NEWTON VICTOR, LTD. had on show a new model of their Raymax unit, suitable for continuous operation at 90 mA, 50 kVp. and incorporating a rotating-anode tube based on Dr. A. Taylor's design. The fact that such a tube must be water cooled involved the development of a rotating vacuum seal which was accomplished by the use of Gaco hard rubber knife-edge seals separated by Apiezon low vapour pressure grease. The anode which is rotated at about 900 r.p.m. is in the form of a cone with a 6° half-angle, so that a camera mounted on one side of the tube has the collimator normal to the side of the X-ray tube, thus providing space for larger and more complicated cameras. The beam emitted from the other window of the tube is at an angle of 12° and this can be used without increasing the specimen-target distance for powder work and other techniques using small cameras. The unit is of the continuously evacuated type and the target material can easily be changed.

The PHILIPS X-ray diffraction unit exhibited consists of an H.T. transformer unit with an output of 60 kV. 20 mA. to which a sealed-off X-ray tube is directly attached at the H.T. terminal. The anode of the tube is grounded and arranged for mains water cooling. The tube is of the four-window type and can easily be exchanged for another with a different target material. Machined faces in the vicinity of the tube apertures permit the attachment of camera tracks and a circular table for other types of camera is also provided.

UNICAM INSTRUMENTS (CAMBRIDGE), LTD. had on show a single crystal Weissenberg goniometer and a Geiger counter spectrometer for the X-ray analysis of single crystal and powder specimens. The former consists of a goniometer head capable of rotation about an axis coincident with the axis of a cylindrical camera and the movements of the head and camera are coupled together. The head carries the standard Unicam graduated arcs and slides and may readily be detached from the instrument. The standard camera is 57·3 mm. in diameter, but a 60 mm. camera can be fitted if specially required. Any angle of oscillation between a few degrees and 200° can be obtained and the translation of the camera when coupled to the rotation of the crystal is 1 mm. per 2° rotation. For taking oscillation photographs during the initial setting of the camera, the camera slide may be disconnected from the driving unit. Conversely the camera may be translated when the head is stationary. For taking inclination Weissenberg photographs, the upper base is pivoted on the lower base and can be rotated up to 30° on either side of the normal setting or up to 40° if a special bracket is used. The great range of movement of the upper base allows an almost complete survey of all possible X-ray reflections from a crystal with one setting. A further feature of value is that the instrument may be moved out of the X-ray beam without upsetting the alignment.

The Geiger counter spectrometer shown comprises a spectrometer base provided with two motor-driven horizontal rotating movements reading to within one minute of arc; a vertical circle and goniometric crystal holder suitable for Laue and rotating crystal methods; a monochromator with variable slits and filters; a Geiger counter unit with mounting brackets capable of vertical angular movement of 30° above and 5° below horizontal and horizontal movement through an arc of 150°; and an electronic amplifier and scaling unit.

Other exhibits included a high-temperature powder camera suitable for investigations up to 1,000° C.

For very high temperature work, THE PLESSEY CO., LTD. exhibited a 19-cm. diameter camera with a tungsten wire furnace suitable for operation in a reducing atmosphere up to temperatures in excess of 1,800° C. A fully adjustable slit system is incorporated.

Primarily intended for use with the H.R.X. diffraction unit, semi-cylindrical X-ray cameras were displayed by the Hilger Division of HILGER & WATTS, LTD. A set of three has diameters of 60, 114·6 and 190 mm. and the exposed portion of the film in each case is 70 mm. wide. Each has a height adjustment and is provided with mechanism for oscillating block specimens and for rotating wire or fibre specimens.

Electron Microscopy

In the design of the most recent model of the METROPOLITAN-VICKERS electron microscope, the EM4, the aim has been to simplify manufacture and reduce controls to a minimum, to maintain a high performance comparable with the EM3 and to produce a small self-contained instrument suitable for routine work. Resolution obtainable is 100 Å, compared with 50 Å for the EM3. The EM4 has a multiple lens image-forming system, which provides a magnification range covering approximately 1,000 × to 20,000 × by lens current control, and which permits a compact design of stack, which, in this instrument is horizontal and housed in the top of the desk. A specimen airlock reduces pumping to ½ minute after a specimen change. The specimen holder takes three standard 3-mm. diameter grids and the mechanical stage has adequate movement to cover all parts of these. Designed for 70-mm. film, a single loading of the camera gives at least 15 exposures. After reloading the camera, pumping down time is 10 minutes including film degassing. The electron source is a self-biased hot-cathode gun integral with the condenser lens.

Provision is made for stereo-micrography which is made possible by the great depth of focus of the electron microscope. Examples of stereoscopic micrograms taken on an EM3 instrument were displayed by the ASSOCIATED ELECTRICAL INDUSTRIES' RESEARCH LABORATORY.

The instrument exhibited by THE PLESSEY CO., LTD. is of the vertical type and the three electromagnetic lenses cover a range of magnification from 50 × to 20,000 ×. The objective lens may be corrected for residual astigmation, by means of external controls, while the instrument is running. Increased contrast is obtained by using objective apertures as small as 10 microns, which can be rapidly centred by external controls and changed in a few minutes. These features together with air-lock provision on the specimen and photographic chambers reduce setting-up time considerably. Methodical examination of specimens is made possible by calibration of the specimen stage.

Electron diffraction may be carried out both by reflection and transmission, and the special unit construction of the instrument permits a choice of any, or all, of the features mentioned. The design is such that modification to meet scientific advances or special requirements is readily effected.

For the purpose of determining the topography of replicas of metallurgical specimens examined by the electron microscope a shadow casting technique is adopted. W. EDWARDS & CO. (LONDON), LTD. have developed for this purpose an accessory for their Model 12E coating plant. The angle between the specimen surface and the evaporating source is measured by a protractor secured to the workholder. The specimens are secured in a demountable clamp which can be conveniently used for holding the specimens during other processing.

The same firm have developed an accessory for the Model 6E miniature evaporating unit to enable metallurgical specimens, whether for optical or electron microscopy, to be cathodically etched by bombardment with positive ions in a glow discharge.

Optical Microscopy

The Vickers projection microscope, well known to metallurgists, was shown by COOKE, TROUGHTON & SIMMS, LTD. The cabinet has now been re-designed to permit the use of the instrument from a sitting position and arm rests are provided. A further improvement has been effected in the ball-bearing fine focusing movement. Also exhibited by this firm was a phase-contrast microscope for opaque specimens. The illuminator tube carries the annulus which is used for all objectives. It can be moved in and out of action and is provided with a centring adjustment. The illuminator tube also contains a condensing lens and is fitted with a variable power adjustment whereby the phase plates in objectives of different powers may be made to coincide with the single annulus. Each objective is fitted with an adjustable incident illuminator plate and the necessary phase plate.

The exhibits of R. & J. BECK, LTD. included three items of metallurgical interest. The No. 50 Universal microscope shown was the model for both transmitted and vertical illumination. As far as possible the instrument is constructed as a complete unit with a minimum of attachable parts. The change from monocular to binocular vision is made by rotating the two bodies in their turret, and the change from visual observation to projection or photography by a simple movement. In this way rigidity and freedom from vibration are assured.

The metallurgical bench microscope shown has been completely re-designed and is constructed on very robust lines. It is made in monocular and binocular forms and fitted with a Wrighton illuminator. The object glasses are " bloomed " to improve their performance with opaque illumination.

For macro work a substantially constructed apparatus for direct photography at low powers was exhibited. Arrangements are provided for illumination of both transparent and opaque objects. The quarter plate camera has a series of anastigmatic lenses of 0·5, 0·9, 1·65 and 3·25 in. focal length and, for photographing at larger magnifications, the apparatus is so made that a microscope can be utilised.

Considerable developments have taken place in the last few years in the reflecting microscope with its large working distance and THE BRITISH IRON & STEEL RESEARCH ASSOCIATION showed an instrument of this type designed for the microscopic examination of metals at high temperatures. In this instrument an optical system of unit magnification, comprising a spherical mirror and a half-silvered plane, produces a real image of the specimen; this optical system has a N.A. of 0·7 and a working distance of 1·7 cm. The real image thus produced, although not magnified, is accessible, whereas the heated specimen is not, and the image may be examined by an ordinary microscope. The specimen is illuminated obliquely, the light being introduced through the bottom of the furnace, and the optical components of the illuminator are mounted inside the vacuum furnace.

Laboratory Furnaces and Ovens

Most of the laboratory furnaces exhibited were of the tube or muffle type, controlled by an energy regulator. A. GALLENKAMP & CO., LTD. showed three furnaces, one muffle and two tube type, all electrically heated. The

Plessey electron microscope.

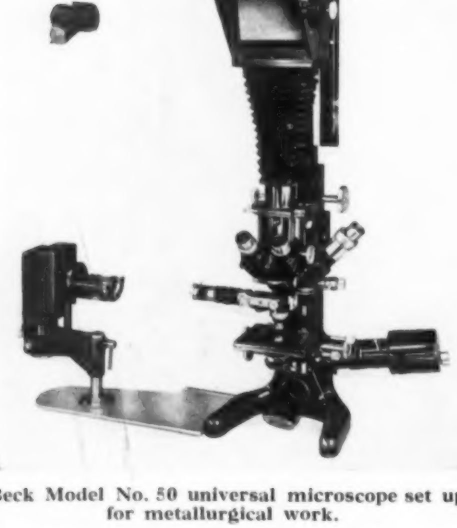
muffle has a 6 in. × 3 in. × 3 in. chamber and a maximum operating temperature of 1,000° C. Temperature is controlled by an energy regulator and indicated on a 2¼-in. instrument fitted in the skirt. For operation at temperatures up to 1,250° C., a tube furnace heated by a heavy spiral element, running at less than 20 volts and supplied from a multi-tapped built-in transformer, was shown, whilst for higher temperatures (up to 1,400° C.) there was a silicon-carbide element tube furnace, again supplied from a multi-tapped transformer.

The salient feature of a tube furnace shown by GRIFFIN & TATLOCK, LTD. is the use of an inexpensive heavy gauge alloy element which is self supporting and can be replaced in a few moments. The bore is ⅞ in. and a length of 10 in. is heated. For continuous running 1,150° C. is the maximum temperature, but for short periods it can be run at 1,200° C. Built into the base of the casing are the supply transformer, a Simmerstat and a 4-in. indicator reading to 1,400° C. A double-tube model is also available.

A range of muffle furnaces shown by A.E.W., LTD. are suitable for temperatures up to 1,250° C. and are fitted with replaceable elements running in channels in refractory bars. The latter interlock to form the chamber and are replaceable. A Simmerstat is built into the casing.

A crucible furnace shown by this firm is suitable for operation at temperatures up to 1,250° C. with hydrogen or other gaseous atmosphere. The chamber consists of a vertical quartz cylinder sealed at the bottom and wound with a low voltage element. The top of the chamber is fitted with a sand seal and the " atmosphere " enters at the bottom and leaves by a small tube in the lid. An energy regulator operates in the primary of the transformer and a pyrometer completes the equipment.

A display of high-temperature refractories was featured by THE THERMAL SYNDICATE, LTD. These included pure oxide refractory ware made from alumina, magnesia, thoria and zirconia for use at very high temperatures (above 1,500° C. and in some cases even above 2,000° C.). Thermal mullite 525 ware and combustion tubes for use up to 1,500° C., and new mullite for use up to 1,700° C., together with zircon were were also shown.



Beck Model No. 50 universal microscope set up for metallurgical work.

For temperatures up to 320° C. A.E.W., LTD. showed a laboratory oven made in all sizes and fitted with flame-proof elements. Uniformity of temperature is achieved by forced air circulation and thermostatic control to any desired accuracy can be fitted.

The electric laboratory oven exhibited by J. W. TOWERS & CO., LTD. has an outer case of enamelled sheet steel and an inner oven of stainless steel, the whole oven, including the door being insulated with glass silk. The heating elements are flame-proof and temperature control is effected by a bimetallic thermostat to ± 1° C. over the range 40°–180° C.

TOWNSON & MERCER, LTD. exhibited a refrigerated brine tank and circulator system for supplying cooling liquid down to 0° C. or even lower, to any external apparatus. The refrigerator unit, of the compressor type, is housed in the base with a thoroughly insulated cold tank above, which can contain brine or other liquid. This tank is connected by thermostat to the refrigerator and a pump and valve assembly is built into the unit so that the cooled liquid can be pumped through any apparatus it is designed to cool. The cold tank itself is big enough to be used for maintaining quite large objects at any desired cold temperature.

Temperature Measurement and Control

A new instrument for indicating surface temperatures of rapidly rotating or moving bodies within the range of 200°–1,000° C. was shown by ELECTRONIC INSTRUMENTS, LTD. A lead sulphide cell is used in the pick-up head and indications are shown on a cathode-ray tube which may be scaled in ° C. The whole apparatus, which has been developed in conjunction with Ferodo, Ltd., is designed to be portable and will work off mains or a low-tension battery.

In the LYDIATE ASH LABORATORIES electronic high-temperature indicator, a narrow beam of pulsed supersonic energy is transmitted across the high-temperature zone and the velocity of propagation determined. Temperatures of the order of 2,000° C. are indicated directly on a cathode ray tube by means of a partly " blacked-out " circular trace. Means are provided for making corrections based on the analysis of the gases present.

In the resistance thermometer controller shown by SUNVIC CONTROLS, LTD. a circuit containing a gas-filled tetrode valve is arranged to cycle so that current is taken by the valve for about 15 seconds and then ceases for 15 seconds, the cycle repeating itself. The control circuit of a vacuum switch is included in the anode of the gas-filled tetrode, the contacts of the switch being connected in the furnace circuit. The out-of-balance voltage of a resistance bridge containing a resistance thermometer is fed to an A.C. amplifier, the output of which is connected in the grid circuit of the gas-filled tetrode. The amplifier output is proportional to the bridge input signal, and is arranged to be in quadrature with the anode voltage of the tetrode. The amplified signal modifies the natural cycle times of the circuit mentioned above and the percentage " ON " time is arranged to be approximately proportional to the error

or bridge signal. Proportional temperature control is thereby applied to the furnace. This controller has found considerable application in the control of creep-testing furnaces.

Other Sunvic exhibits included a number of bi-metal thermostats featuring proportional control; continuous adjustment from 0°–300° C.; right-angle drive; and flexible drive with negligible backlash. For temperatures up to 500° C. a differential stem-type thermostat fitted with proportional control was shown. To replace thermos flasks for thermocouple cold junctions, Sunvic have developed a cold junction thermostat, with a ¾ in. diameter control chamber, which maintains an accuracy better than $\pm$ 0·1° C.

Two energy regulators, type ERL, similar to ERH but with a special cam to allow linear adjustment of input, and type TYW for wall mounting and incorporating a standard three-pin socket outlet were also displayed.

To meet the need for recording a number of rapidly changing temperatures, Nash & Thompson, Ltd. have developed a multipoint rapid temperature recorder, designed to record the temperature indications of as many as twenty thermocouples. The set of couples is "scanned" in 6 seconds so that the E.M.F. from each in turn is fed to a "chopper" type D.C. amplifier. The amplified voltages are photographically recorded on a cathode-ray oscillograph. Provision is made for the simultaneous recording of standardising E.M.F.'s. In order to conserve film when long runs with less rapid temperature changes have to be recorded, provision is made for recording only every *n*th scan, where *n* is selected by switch from a range of values. For visual work another type of display may be selected, in which the traces of any one scan are spread across the screen.

An automatic temperature controller based on electronic principles was shown by J. W. Towers & Co., Ltd. It is operated by a thermocouple, the pyrometer indicator of which is fitted with an additional pointer which is set at the required control temperature. This pointer is connected to a Fielden Tektor Meter Relay circuit, and when the temperature indicating pointer reaches it, the electrical capacity of the circuit is affected and a relay operated. An accuracy to within 1% of the scale range, or better, is attainable.

The exhibits of Elliott Brothers (London), Ltd. included the Elliottronic automatic potentiometer recorder, a self-balancing instrument. A small D.C. signal is amplified and inverted to A.C. by a magnetic inverter, a form of variable impedance transformer. The sensitive detector circuit includes no moving parts or contacts other than the slidewire contact which is driven by a robust balancing motor supplied from a simple A.C. amplifier. The slidewire contact carriage is integral with the pen and pointer assembly and a pen speed of 3½ seconds for traversing the 10-in. scale span is attained. Accuracy of measurement is to within ¼% full scale, whilst the sensitivity is of the order of 0·2% full scale. When used as a controller, the potentiometer is fitted with an electrical proportionating circuit which provides a D.C. output whose magnitude and direction correspond to the "deviation" of the control variable. This electrical connection enables the control mechanism to be housed remote from the controller if required.

A further Elliott exhibit was a high-speed radiation pyrometer for measuring the temperature of steel strip

A.E.W. laboratory furnace.

and sections during rolling. A quartz lens concentrates radiation from the hot body on to a high-speed thermocouple, the E.M.F. being amplified by a galvanometer-photocell circuit to give an output capable of operating a direct writing recorder. The instrument responds to 98% of a temperature change in ¾ second.

Three applications of the "Land" principle of surface pyrometry were shown by the British Iron & Steel Research Association: one inside-plated with platinum, with a calibrated thermopile for measurement; one back-silvered glass, with a calibrated photoelectric cell; and the other with a silvered hemisphere and a photo-emissive cell. The last type was developed for the continuous measurement of hot-rolled strip temperatures.

Another B.I.S.R.A. exhibit, an instrument for continuously measuring the temperature of wire as it is being drawn, consists of two beads, whose resistivity is sensitive to temperature changes, embedded inside a small annulus. The annulus is mounted at the exit of the drawing die, in such a way that the drawn wire passes through but does not touch it. The heat radiated from the wire is picked up by the beads and the emissivity is electrically recorded. This technique has been developed in connection with investigations into the effects of various drawing temperatures on the mechanical properties of the finished wire.

Two thermocouple potentiometers were shown by the Doran Instrument Co., Ltd. The first, primarily intended for accurate temperature measurement, measures from 10 microvolts to 50 or 100 millivolts in two ranges. It can also be supplied with a potential divider for checking indicator calibrations. The Mini thermocouple potentiometer is similar but smaller and is mounted in a bakelite case with lid and carrying strap.

Other exhibits of interest were a miniature snap action thermostat, free of radio interference and incorporating a miniature permanent magnet, shown by Electrothermal Engineering, Ltd.; precision leaf-type rotary switches, suitable for switching banks of thermocouples, with up to 101 contacts single-pole type and 50 contacts double-pole type, shown by W. G.

PYE & Co., LTD.; a PLESSEY multipin thermocouple connector, comprising twenty 7-amp. and four 19-amp. pins, 12 of brass and 12 constantan, and providing 12 thermocouple connections in one housing; and a display of precious metal thermocouples and thermocouple wire by JOHNSON, MATTHEY & Co., LTD.

Mechanical Testing

In the photoelasticity polaroscope shown by TECHNE (CAMBRIDGE), LTD., the polarizer and analyser are coupled together and each 10° of rotation indicated by a "click" mechanism. The quarter wave plates are carried in rotatable mounts so that they can instantly be brought into use. Other features are the use of a miniature camera to reduce exposure times, an improved straining frame operated by compressed air, and the grouping of all controls so that they can be operated from one position, behind the screen on which the isoclinics can be drawn.

The use of electrical resistance strain gauges has increased rapidly in recent years and several exhibits were shown in this field. J. LANGHAM THOMPSON & Co. showed carrier frequency strain gauge measuring equipment capable of measuring static or dynamic strains as low as 10^{-7}, together with a complete range of strain gauge pick-ups.

Unbonded strain gauge units were also shown in which one end of each of four elements is connected to a frame and another to an armature. The force or movement to be measured is applied to the armature and the construction is such that this unbalances the Wheatstone bridge formed by the four elements, as two will be in compression and two in tension.

NAGARD, LTD. exhibited their Type W1 electronic strain gauge head capable of measuring displacements in the range 1–5,000 microns by a combination of the gauge head and a D.C. amplifier type 103/A3.

The SOUTHERN INSTRUMENTS universal strain gauge bridge (Type M726) is intended for use with the MR235 drift-corrected D.C. amplifier, and provides for using single gauges, matched pairs or complete bridges.

Mechanical variables require to be translated into electrical quantities for recording, and in the KELVIN & HUGHES single-channel dynamic strain recorder variable-impedance conversion elements are used for the purpose. The equipment comprises two units, one containing the bridge circuit, 2 kc/s. oscillator, carrier amplifier, demodulator, D.C. amplifier and power supplies, while the recorder forms the second unit. The recorder uses 55 mm. Teledeltos paper driven by a synchronous motor through a two speed gearbox. An auxiliary gearbox also fitted enables three pairs of speeds between 0·25 and 10 cm./sec. to be obtained.

Both portable direct reading strain gauge bridges exhibited by H. TINSLEY & Co., LTD. can be used with gauges with gauge factors in the range 1·8–2·4 and have self-contained apex resistors suitable for a single-gauge circuit. By the addition of an external apex unit they can be used for multiple-gauge circuits. One has a 6-in. dial calibrated directly in strain, and four ranges, ± 0·5%, ± 0·25%, ± 0·1% and ± 0·05% strain, whilst the other has a 10-cm. strain-calibrated scale and two ranges, ± 0·5% and ± 0·1% strain. Tinsley also showed a new strain gauge which will give linear response and consistent results for strains up to 4%.

The COOKE, TROUGHTON & SIMMS micro-hardness tester was shown fitted to the Vicker's projection microscope. It has a diamond indenter of the Vicker's type mounted in the front lens of the objective and loads of 1–500 gm. can be applied.

Other micro-hardness testers were exhibited by HALL TELEPHONE ACCESSORIES, LTD., one for use with an inverted microscope and with loads up to 300 gm. and the other for use with a bench type microscope and loads up to 100 gm. Both instruments use a Vicker's pyramid indenter, and the bench microscope is fitted with a special type of mechanical stage of high accuracy. The bench type equipment consists of a turret head with positive indexing, carrying a pivoted beam and two centralising objective adaptors. Once fitted to the microscope tube, there is no need to remove the accessory in order to use the microscope for its normal purpose.

The macro-micro hardness tester shown by INDUSTRIAL DISTRIBUTORS (SALES), LTD., uses dead-weight loading, can accommodate quite large specimens and has all its sensitive operations carried out automatically. The indenter consists of a double-conical diamond of 2 mm. radius and 154° included angle and the measuring microscope is inclined at 45° to the test surface.

Fatigue-testing equipment of the electromagnetically excited type was exhibited by SUNVIC CONTROLS, LTD. and DE HAVILLAND PROPELLERS, LTD.

Miscellaneous

Developed in the Company's Research Department for making automatic records of thermal expansion effects in metal and other specimens, a dilation temperature recorder was exhibited by the METROPOLITAN-VICKERS ELECTRICAL Co., LTD. The instrument is adapted from a Kent Multilec temperature recorder, the temperature being recorded by a pen moving across a chart on a plane table. A second measuring unit, operated by a conventional dilatometer incorporating a remote-reading dial micrometer, causes the table to traverse, in accordance with the length change of the specimen, in a direction at right angles to the line of movement of the pen. A dilation-temperature record is thus obtained. The original time-base chart mechanism of the Multilec recorder is retained, so that a temperature-time record is also provided. Alternatively, by the mechanical coupling provided, the dilation may be recorded against time, enabling the instrument to be used for such purposes as the study of length changes at constant temperature.

Two vacuum pumps were exhibited by METROPOLITAN-VICKERS, one rotary and one of the oil-diffusion type. The "Metrovac" S.R.3 is a single stage oil-sealed rotary pump with a speed of 600 r.p.m. The displacement is 6½ litres per sec., pumping speed 5½ litres per sec. and the ultimate pressure obtained 10/20 microns, measured by a Pirani gauge in a normal practical system. The 043C oil-diffusion pump has a pumping speed of at least 250 litres per sec. below a pressure of 10^{-4} mm. Hg. and the maximum backing pressure for optimum operation is 0·2 mm. Hg. at a fore-pressure of 3×10^{-4} mm. Hg. These performance figures were obtained with the standard 6-in. diameter water-cooled baffle plate.

Vacuum equipment is a major product of W. EDWARDS & Co. (LONDON), LTD., who had several items on show. A new 16-in. diameter four-stage oil-diffusion pump with a speed of 5,000–6,000 litres per sec. was exhibited along with its associated high-speed isolation valve. Other diffusion pumps shown included a self-purifying metal pump with an interesting new fractionating

Vitreosil Mercury Vapour Jet Pumps.

arrangement capable of attaining a pressure of the order of 10^{-7} mm. Hg., at a speed of 70–80 litres per sec. and a maximum backing pressure of 0·5 mm. Hg.; a 1-in. bore laboratory mercury pump; and a two-stage glass mercury pump (Type G.M.2) with a speed of 12 litres per sec. The Speedivac range of rotary pumps has been extended by the introduction of the single-stage Model 1S450A, having a displacement of 450 litres per min. and ultimate vacuum of 0·005 mm. Hg. (McLeod Gauge).

Various types of vacuum gauge were also shown, including an improved sensitivity Philips' gauge calibrated to 5×10^{-7} mm. Hg.; a combined Philips' and Pirani type gauge covering the range 10–10^{-5} mm. Hg.; a miniature Pirani gauge calibrated from 0·5–0·001 mm. Hg.; and an improved low-pressure McLeod gauge whose range is extended to 10^{-6} mm. Hg., accuracy of reading being assisted by a needle valve for fine control of the air supply, a silvered scale and cursor with magnifying lens.

Other Edwards exhibits included a vacuum controller of the thermal conductivity type enabling a series of events to be initiated by pre-set pressures in a vacuum system; an automatic pumping plant suitable for the continuous production of electronic devices, vacuum coating and vacuum brazing; and a vacuum hot plate.

The THERMAL SYNDICATE, LTD. exhibited a complete high-vacuum system consisting of a new Vitreosil single-stage (or two-stage) umbrella jet-type mercury pump and a Vitreosil M.V. fore pump operated in conjunction with an ordinary water-filter pump, whilst ELECTROTHERMAL ENGINEERING, LTD. showed a mercury diffusion pump fitted with an electric pump heater consisting of a knitted glass fabric to which is attached a coiled coil-heating element insulated by glass-fibre. The unit covers the whole flask surface and eliminates bumping.

For mounting microspecimens in thermoplastics, GRIFFIN & TATLOCK, LTD. exhibited a mounting press in which pressure is applied by a plunger actuated by a screw thread. Internal heating and cooling systems are incorporated.

For measuring the thickness of a layer of paint or other non-magnetic coating on any material with magnetic properties between the extremes of cast iron and electrical sheet steel, without damaging the coating, SALFORD ELECTRICAL INSTRUMENTS, LTD. showed their layer thickness meter which is calibrated from 0–0·030 in. and has an accuracy within ± 10%.

For measuring the thickness of paper, plastic sheets and metal foils, THE BALDWIN INSTRUMENT CO., LTD. showed a β-ray thickness gauge in which β-rays from a radioactive isotope fall on an ionization chamber a short distance away. The absorption of the radiation is a measure of the thickness of the material. As well as gauging material it can be used for continuous indication recording and control of strips. A further radioactive thickness gauge capable of being used for measurement and control was exhibited by E. K. COLE, LTD.

Pilot Plant Research Station

A NEW style research station that will have much of the equipment of a steelworks in miniature is to be begun by the British Iron and Steel Research Association in Sheffield during the next few months. Pilot steelworks plant for melting, rolling, drawing and forging, to try out research results before application to production plant, is to be installed in buildings to be erected on a 2½-acre site at Hoyle Street.

Steel melting will be carried out in a 10-cwt. capacity arc furnace, which will be used for work on sulphur elimination and on problems of electric furnace practice.

A high-speed 14-in. four-high cold-strip rolling mill will enable B.I.S.R.A.'s scientists to carry further their investigations into such things as "roll force," the measurement of which gives rolling-mill makers and users the equivalent of the boiler engineer's steam-pressure gauge in working out safe and economical loads. On a smaller two-high mill valuable work has already been done by B.I.S.R.A.'s rolling section, but there must now be larger, fully instrumented equipment, on which to take this work further.

B.I.S.R.A. will have its own experimental wire-drawing plant in the new buildings, where it will be possible to carry out trials of new processes before they go on to the full-scale production plant. Work on corrosion, steel founding, refractories and other problems will also be carried out

The choice of Sheffield for this important research establishment follows the Association's policy of placing its modern scientific facilities in the main industrial centres. The resulting intimate contact between the industry's manufacturers and scientists ensures that problems can be communicated as soon as they arise, and research programmes can readily be modified to meet the changing needs of industry.

Conference on Isotopes in Industry

THE Department of Extra Mural Studies of the University of Birmingham, in conjunction with the Birmingham Branch of the Atomic Scientists' Association, is holding a Conference on "Isotopes in Industry" from May 19th to May 21st next, at the University, Birmingham.

The Conference is designed to introduce radioactive isotopes and the associated techniques to industrial scientists and technologists. Further details may be obtained from the Department of Extra Mural Studies, University of Birmingham, Edmund Street, Birmingham, 3. Telephone, Central 8541, Extension 12.

Errata

ON page 281 of the March issue the following correction should be made to the second item in the method given:

"(ii) Buffer Solution. This contains 100 g. sodium acetate ($CH_3COONa.3H_2O$) and 30 ml. N. acetic acid in 500 ml."